Instream flow studies on Cliff Creek, a tributary of the Hoback River

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Abstract

Two segments were selected for instream flow water rights filing consideration on Cliff Creek, a tributary of the Hoback River near Bondurant, WY. The segments were selected considering land ownership, hydrology, and stream channel characteristics to maintain or improve the Snake River cutthroat trout (SRC) fishery in this stream. The species is common throughout the Hoback River watershed, which is managed as a wild SRC fishery. This report provides flow recommendations for Cliff Cliff developed from studies conducted in 2008. Two modeling techniques were employed to develop instream flow recommendations for maintaining SRC spawning habitat during spring runoff, Physical Habitat Simulation (PHABSIM) and River 2D. Riffle hydraulic characteristics were examined using the Habitat Retention approach to ensure that flow recommendations from other methods did not impede fish movement. The Habitat Quality Index (HQI) model was used to assess stream flow versus juvenile and adult trout habitat quality relationships in the summer. During the winter months, November through March, natural winter flows were recommended to maintain all life stages. The 20% monthly exceedance, based on hydrologic estimates from HabiTech (2009), was selected to represent natural winter flow. Finally, a dynamic hydrograph model was used to quantify flow needs for maintenance of channel geomorphology.

Approximately 8.5 miles of stream habitat will be directly protected if these two instream flow applications advance to permit status. Recommended flows range from a low of 11 cubic feet per second (cfs) during the winter to 20 cfs during spring in the upper Cliff Creek segment and from 15 cfs in winter to 140 cfs during spring in the lower reach.

Introduction

Guiding Principles for Instream Flow Recommendations

The analyses and interpretation of data collected for this report included consideration of the important components of an aquatic ecosystem and their relationship to stream flow. Stream ecosystems are complex. Many instream flow studies conducted in the 1970s and 1980s overlooked the full breadth of this complexity by focusing solely on sport fish species and maintenance-level instream flow recommendations. This report describes recommendations developed using an ecosystem approach that is consistent with contemporary understanding of stream complexity and effective resource management. The recommendations of the Instream Flow Council (IFC), an organization of state and provincial fishery and wildlife management agencies, provide comprehensive guidance on conducting instream flow studies. The approach described by that organization includes consideration of three policy components (legal, institutional, and public involvement) and five riverine components (hydrology, geomorphology, biology, water quality and connectivity; Annear et al. 2004). Sections of this report were selected to reflect appropriate components of that template as closely as possible. By using the eight components described by the IFC as a guide, we strive to develop instream flow recommendations that work within Wyoming's legal and institutional environment to maintain or improve important aquatic resources for public benefit while also employing a generally recognized flow quantification protocol.

Legal and Institutional Background

The Wyoming Game and Fish Department (WGFD) manages fish and wildlife resources under Title 23 of Wyoming statutes (W.S.). The WGFD was created and placed under the direction and supervision of the Wyoming Game and Fish Commission (Commission) in W.S. 23-1-401 and the responsibilities of the Commission and the WGFD are defined in W.S. 23-1-103. In these and associated statutes, the WGFD is charged with providing ". . . an adequate and flexible system for the control, propagation, management, protection and regulation of all Wyoming wildlife." The WGFD mission statement is: "Conserving Wildlife - Serving People", while the WGFD Fish Division mission statement details a stewardship role toward aquatic resources and the people who enjoy them. In a 2005 policy statement, the Commission formally assigned certain responsibilities for implementing instream flow water rights to the WGFD and specified procedures for notifying the Commission of instream flow filing activities. Briefly, the Department is directed to notify a Commission member when a stream in his or her district is identified as a candidate for filing. If that Commission member has concern about the proposed recommendation, it will be brought to the full Commission in open session. In addition, the Department will advise all Commission members at least two weeks prior to submitting materials for each instream flow filing recommendation, as well as notice of any changes in the Instream Flow Program.

The instream flow law, W.S. 41-3-1001-1014, was passed in 1986 and establishes that "unappropriated water flowing in any stream or drainage in Wyoming may be appropriated for instream flows to maintain or improve existing fisheries and declared a beneficial use..." The statute directs that the Commission is responsible for determining stream flows that will "maintain or improve" important fisheries. The WGFD fulfills this function under the general policy oversight of the Commission. Applications for instream flow water rights are signed and held by the Wyoming Water Development Commission (WWDC) on behalf of the state should the water right be approved by the State Engineer. The priority date for the instream flow water right is the day the application is received by the State Engineer.

One of the critical terms associated with the present instream flow statute relates to the concept of a "fishery." From a natural resource perspective, a fishery includes the habitat and associated natural processes that are required to support fish populations. The primary components that comprise needed physical habitat include, but are not limited to, the stream channel, riparian zone and floodplain as well as the processes of sediment flux and riparian vegetation development that sustain those habitats (Annear et al. 2004). To maintain the existing dynamic character of an entire fishery, instream flow regimes must maintain the stream channel and its functional linkages to the riparian corridor and floodplain to perpetuate habitat structure and ecological function. The State Engineer has concluded that a full range of channel maintenance flow regimes is not consistent with the legislative intent of the instream flow statute. Therefore, until the interpretation of state water law changes, channel maintenance flow recommendations are not included on instream flow applications. Channel maintenance flow requirements are presented in Appendix A of this report and may be useful should opportunities arise in the future to secure a broader, more approporiate range of instream flow water rights for this important fishery management purpose.

Through February 2010, the WGFD has forwarded 110 instream flow water right applications to the WWDC for submission. Of these, the State Engineer has permitted 83 and the Board of Control has adjudicated five.

Purpose for Hoback River Instream Flow Studies and Water Rights

Guidance for selecting instream flow study sites is provided by the WGFD Water Management Unit's five-year plan (for these sites, the 2006–2010 plan [Annear and Dey 2006] was used). The 2006–2010 plan prioritized high quality habitats for instream flow studies and identified Yellowstone cutthroat trout (YSC; *Oncorhynchus clarki bouvieri*) and Snake River cutthroat trout (SRC; *Oncorhynchus clarki behnkei*) as the greatest priority species upon which to focus efforts during this planning period.

Yellowstone cutthroat and SRC were prioritized for instream flow studies, in part, because these cutthroat trout subspecies were recently considered for federal listing as threatened or endangered. Between 1998 and 2006, there were several actions regarding these two subspecies, including a decision to treat the two as "a single entity" (Federal Register 2001, Federal Register 2006). The most recent finding of the U.S. Fish and Wildlife Service was that the species (aggregate of both subspecies) does not warrant endangered species designation (Federal Register 2006). In response to the petition for federal listing of YSC, the WGFD developed significant, targeted management efforts to protect and expand habitat and populations of both YSC and SRC within their historic range (WGFD 2005a) and has participated in multi-state strategic planning efforts (Range-Wide YCT Conservation Team 2009a, 2009b).

Yellowstone cutthroat trout historically occupied Wyoming waters in the Snake River and Yellowstone River drainages, including the tributary Wind/Bighorn and Tongue River drainages (Behnke 1992, Kruse et al. 1997, Dufek et al. 1999, Kruse et al. 2000, May et al. 2003). The range of SRC occurs within the range of the more widely distributed YSC and includes the headwaters of the Snake River and its tributaries (Van Kirk et al. 2006, May et al. 2007). There is some debate about whether YSC and SRC are distinct subspecies (Van Kirk et al. 2006, Sweet 2009). Leary et al. (1987) was not able to differentiate the two subspecies using genetics and Kruse (1998) did not find meristic differences (counting features such as fins rays or scales) between the two subspecies. However, they are morphologically distinct and are not typically found in the same watersheds,so the WGFD manages them individually (Gipson 2006, Sweet 2009).

The prioritization of watersheds and streams for instream flow studies in Wyoming was based on available information on YSC and SRC populations, including genetic status and population demographics. A range-wide status assessment conducted by fisheries biologists from Wyoming, Montana, and Idaho (May et al. 2003, May et al. 2007) identified conservation populations and assessed the relative extinction risk among populations. Of the extant populations in Wyoming, those in the Greybull River, Wood River, and East Fork Wind River were believed to contain genetically pure populations that span a large geographic area (Kruse et al. 2000) and these streams were targeted for instream flow studies during 1997 through 2006. The next watershed in line for priority was the Greys-Hoback and tributaries of these two rivers. These were identified as high priority streams for instream flow studies because much of the watershed contains SRC populations of high genetic purity. Since genetic status of the SRC population was similar within this watershed (predominantly unaltered; Novak et al. 2005), individual streams were selected based on current understanding of their importance to the local SRC population in terms of contributing to the long-term persistence of the population (e.g., does a stream contain important spawning habitat that is regularly used?), the length of stream (longer streams provide greater protection for level of effort expended), and for logistics (streams selected in a small geographic area for a given year can be more efficiently studied). In 2008–2009 studies were conducted on the Hoback River and its tributaries; once efforts are complete in that drainage, the focus will shift to the Greys River and its tributaries.

Public Participation

The general public has several opportunities to be involved in the process of identifying instream flow segments or commenting on instream flow applications. Individuals or groups can inform WGFD of their interest in protecting the fisheries in specific streams or stream segments with instream flow filings. In addition, planning and selection of future instream flow study sites are detailed in the Water Management Unit's annual work schedules and five-year plans, which are available for public review and comment (either upon request or by visiting the WGFD web site at http://gf.state.wy.us/downloads/pdf/Fish/5yearplan2006.pdf). The public is also able to comment on instream flow water rights that have been filed with the State Engineer through public hearings (required by statute) that are conducted by the State Engineer's Office for each proposed instream flow water right. The State Engineer uses these public hearings to gather information for consideration before issuing a decision on the instream flow water right application. To help the public better understand the details of instream flow filings and the public hearing process, WGFD personnel typically conduct an informal information meeting a week or two prior to each public hearing. Additional presentations to community or special interest groups at other times of year also provide opportunity for discussion and learning more about instream flow issues and processes.

Communication with landowners adjacent to or immediately downstream from instream flow segments is vital for sharing information about aquatic resources and proposed instream flow studies. While most instream flow segments are located on public land where unappropriated water remains, nearby or adjacent landowners are typically given the opportunity to allow the state to extend an instream flow segment on the portion or portions of those streams crossing their property. The two instream flow segments selected on Cliff Creek are located entirely on public land and there are no private landowners immediately up or downstream from the segment so landowner communication was not involved in this process.

Objectives

The objectives of this study were to quantify year-round instream flow levels needed to maintain SRC habiat and identify a channel maintenance flow regime needed to maintain long-term trout habitat and related physical and biological processes (Appendix A). The audience for this report is broad and includes the State Engineer and staff, the Water Development Office, aquatic habitat and fishery managers, and non-governmental organizations and individuals interested in instream flow water rights and SRC management in general or in the Hoback River watershed in particular.

Study Area

Hoback River Basin Description

The Hoback River enters the Snake River at Hoback Junction, approximately 17 miles downstream of the Highway 189 crossing in Wilson, Wyoming (FIGURE 1). The basin includes two separate watersheds classified at the 5th level hydrologic unit code (HUC) scale, the upper (HUC 1704010303) and lower (HUC 1704010304) Hoback River. In total, the two watersheds comprise an area of 566 square miles, which is about 10% of the Snake River headwaters basin (HUC 170401) area. Land ownership in the watershed includes 5.3% private land and 94.7% public land. The public land includes 94.3% Forest Service land and 0.4% Bureau of Land Management land. Recreational uses in the drainage include wildlife observation, hiking, fishing, camping, hunting, floating the river, horseback riding and packing, cross country skiing, snow machine riding, and snowshoeing.

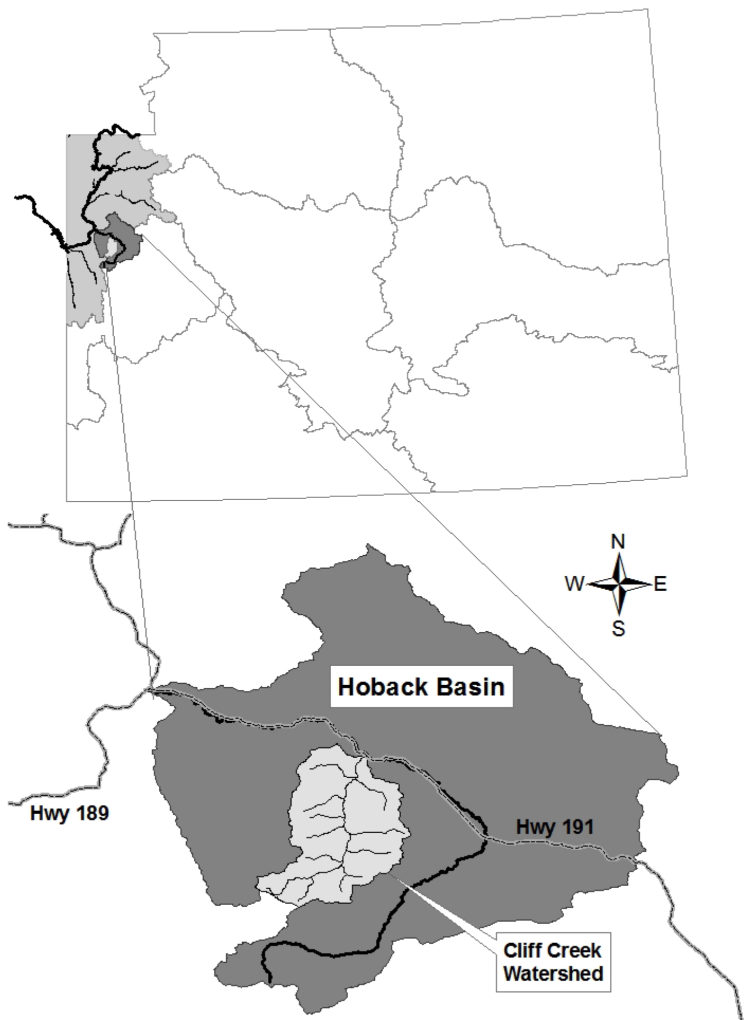

FIGURE 1. Location of Cliff Creek, Wyoming (Snake River 10-digit HUC 1704010304).

The Hoback River basin elevation ranges from 5,900 ft at the mouth of the Hoback River to 11,682 ft at Doubletop Peak in the Dell Creek watershed. There are several tributaries in the Hoback watershed where glacial influence resulted in U-shaped valleys (Rosgen valley type V) and others with more gradual sloping sides (Rosgen type II). The Hoback River itself travels predominantly east to west through a series of north-south oriented mountains and this results in more valleys with gradual sloping sides. However, there are some areas (in the middle and lower parts of the river) that have well developed floodplains (Rosgen Type VIII valleys). Stream channels throughout the Hoback River basin would be primarily classified as Rosgen type "B" and "C" from inspection of 1:24,000 scale topographic maps. There are also some braided "D" channels in those places where the valleys are not constricted and a wide floodplain is present.

The climate in this watershed includes annual precipitation that averaged 21.1 inches in the town of Bondurant over the period 1948–2005 according to data from the Western Regional Climate Center (WRCC 2011). Much of the precipitation falls as snow with an average of 138.7 inches annually from 1948–2005. The average minimum air temperature was 15.9°F and the average maximum was 50.7°F in that same period. Winter conditions typically result in widespread frazil and anchor ice development and this likely impacts over-winter habitat for fish, particularly in altered and unstable stream reaches.

As part of its strategic habitat plan (SHP), the WGFD has prioritized the upper Hoback watershed is a "crucial habitat area" for aquatic habitat and the lower Hoback basin is an "enhancement habitat area" for aquatic habitat in the Jackson Region (WGFD 2009). According to the SHP, "crucial habitats have the highest biological values, which should be protected and managed to maintain healthy, viable populations of terrestrial and aquatic wildlife. These include habitats that need to be maintained as well as habitats that have deteriorated and should be enhanced or restored." The plan also states that enhancement areas "are important wildlife areas that can or should be actively enhanced or improved by WGFD and partners over the next few years if opportunities exist."

Geology

The Hoback River Basin lies within the overthrust belt region of the state, which is described as "a series of large overthrust sheets of rock that overlap one another like shingles on a roof." This region is a short section of a longer trend of thrust faults and folds that extend approximately 5,000 miles between Alaska and Mexico (Lageson and Spearing 1996). These faults are relatively shallow and flat and do not cut into Precambrian basement rocks. The exposed rocks in this watershed are primarily sandstone and shale (Eocene Wasatch formation) which were deposited as stream and floodplain sediments (Lageson and Spearing 1996). The soils are mainly characterized as gravelly sandy loams (BLM 2003). The Hoback River watershed also has evidence of being influenced by glaciers with some valleys in the watershed displaying characteristic U-shaped cross-sectional profiles (e.g., Granite Creek). The resulting glacial deposits can be seen in the floodplains and in many areas resulted in coarse gravel-cobble glacial outwash.

Steep, unstable slopes are common in portions of the watershed and mass wasting events are common. In addition, the highly erodible sedimentary rocks contribute substantial sediment loads to the Hoback River and its tributaries during spring runoff. Additional sediment inputs result from land management practices (grazing and channel alterations) and road construction activities in the watershed. The high sediment loads result in unstable stream channels such that pool development is limited and the stream channels are dominated by a series of long runs and riffles. A lack of pool-forming large woody debris in many locations also contributes to a lack of pools. However, where large woody debris is abundant (e.g., Shoal Creek) pools are more common. Also, beaver activity enhances instream habitat complexity in some locations (e.g., portions of Granite Creek and North Fork Fisherman Creek).

Upland and Riparian Resources

Vegetation in the Hoback River basin is primarily alpine and sub-alpine forest types with lodgepole pine, whitebark pine, limber pine, aspen, Douglas-fir, subalpine fir, Englemann spruce, and blue spruce. The highest elevations in the watershed contain alpine moss-lichen-forb communities. Mountain big sagebrush is the dominant vegetation type in lower elevations. There are several grasses and forbs associated with the sagebrush community including: Idaho fescue, Letterman's needlegrass, elk sedge, sulphur buckwheat, yarrow, rockcress, and lupine. Riparian habitats are predominantly willow communities with four common willow species (coyote, Booth's, Drummond's, and wolf). Cottonwoods are present but very sparse in this region. A common noxious weed in the watershed, particularly in riparian areas, is Canada thistle.

There were substantial changes in vegetation communities in the Greys-Hoback watershed in recent years. Whitebark pine historically dominated upper forest ecotones in the Bridger-Teton National Forest (BTNF 2009); however, much of that (up to 95 percent) has been lost due to the exotic blister rust fungus, mountain pine beetles, and effects of an altered fire regime (CH2MHill 2004). Mountain mahogany also used to be much more prevalent in the Greys-Hoback watershed but nearly all of it was lost due to the effects of an altered fire regime (CH2MHill 2004). In addition, lodgepole pine are currently suffering dramatic losses in the BTNF due to very high levels of mountain pine beetles; at least 75 percent of these trees are currently mature and susceptible to infestation (BTNF 2009). Grazing has also impacted the Greys-Hoback watershed, especially riparian areas, through changes in plant species composition, diversity, and density and contributing to the high soil erosion (NPCC 2005).

Hydrology

Two USGS gages operated historically in the Hoback River watershed, but neither is currently in use. A gage was operated in the Lower Hoback (13019500) from 1944–1958 and another in Little Granite Creek (13019438) from 1981–1992. Neither gage provides an ideal reference for all streams in the Hoback River. The mainstem gage was operational for only a short time and does not capture the range of variability among smaller watersheds. The gage on Little Granite Creek was operational for a longer time period (though still relatively short) and that watershed is small with characteristics that differ from many streams in the watershed. With limited options available, the Little Granite Creek gage was chosen as the more representative gage for streams in the Hoback watershed (HabiTech 2009). Stream flow at the Little Granite Creek gage is typical of snowmelt runoff streams with short periods of high (runoff) flow and a substantial portion of the annual flow as a low (base) flow (FIGURE 2). Annual peak flow occurred between May 1 and June 15 over the period of record (median date was May 28). Base flow recession occurs throughout summer with near base flow levels attained by September. Annual flow minima occurred in winter (December, January, or February [FIGURE 3]).

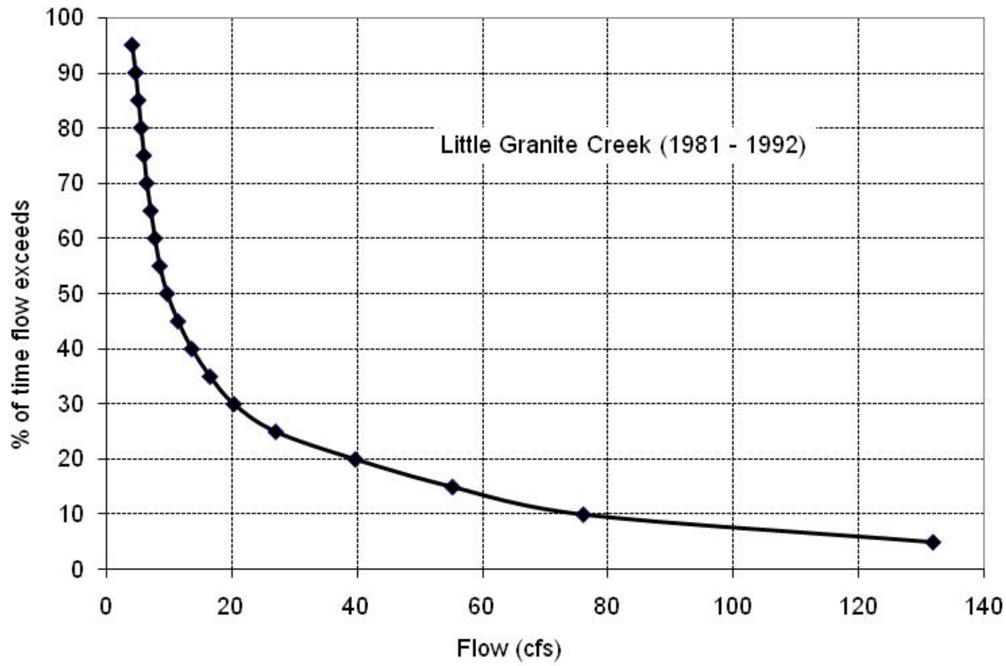

FIGURE 2. Flow exceedance curves for the Little Granite Creek USGS stream gage station (13019438) over the period of record (1981–1992; developed from Table 3 in HabiTech 2009).

Annual stream flow variability (ASFV) and critical period stream flow (CPSF) as defined in Binns and Eiserman (1979) are two measures that characterize local hydrology (TABLE 1). Annual stream flow variability is the ratio of the instantaneous annual peak flow to the annual low flow, and averages 78.3 at the Little Granite Creek gage (1982–1992). On a rating scale of 0–4, this value scores a '2' and is typical of snowmelt dominated streams. As the ASFV ratio increases (greater fluctuation in annual flow) trout suitability diminishes; when the ratio exceeds 100, a score of '1' results (Binns 1982). Conversely, habitat suitability increases with lower ASFV scores (more consistent flow) and the threshold for a score of '3' is a ratio below 40. The CPSF is the average August 1 through September 15 flow expressed as a percent of average daily flow and averages 45.5% at the Little Granite Creek gage (1982-1992). This CPSF value scores a '3' on the rating scale and is indicative of relatively high flow levels in late summer. Sites with such flow conditions in late summer are more likely to maintain trout habitat compared to streams with lower summer flows.

Adjudicated irrigation diversions total 31.87 cfs in the Hoback River and 56.96 cfs in the Hoback River watershed with priority dates ranging from 1895 to 1993. There are no adjudicated water rights in the Cliff Creek watershed.

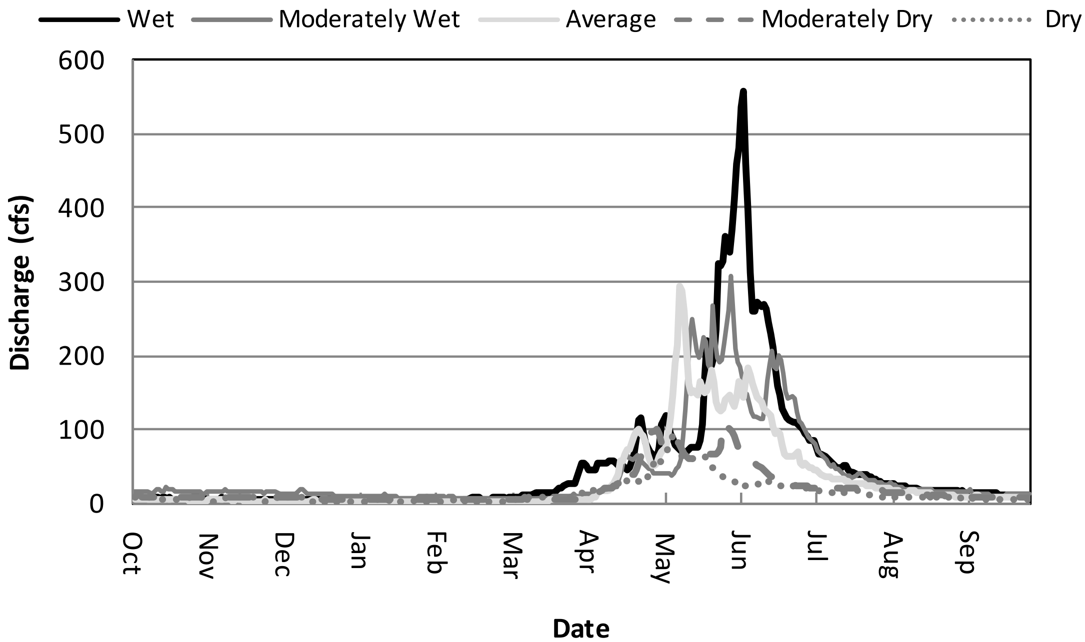

FIGURE 3. Hydrographs for representative wet, moderately wet, average, moderately dry, and dry water years (WY) from the Little Granite Creek USGS stream gage station (13019438). A representative year was randomly selected from within each of three flow exceedence classes (wet 0–10%, moderately wet 10–30%, average 30–70%, and moderately dry 70–90%, and dry 90–100%; HabiTech 2009).

TABLE 1. Hydrologic statistics from the Little Granite Creek stream gage station (13019438).

	Annual Stream Flow Variability (ASFV; annual peak flow / lowest daily flow)	**Critical Period Stream Flow (CPSF; Aug 1 – Sep 15 average flow / average annual flow)**
Mean	Ratio = 78.3	45.5 %
Range	23–169	34.8–56.6 %
n (years)	11	11

Fish and Other Aquatic Resources

The fish community in the Hoback River basin includes two native game species, SRC and MWF (*Prosopium williamsoni*). Other native species include mountain sucker (MTS; *Catostomus platyrhynchus*), longnose dace (LND; *Rhinichthys cataractae*), speckled dace (SPD; *Rhinichthys osculus*), Pauite sculpin (PSC; *Cottus beldingi*), mottled sculpin (MSC; *Cottus bairdi*), and Utah sucker (UTS; *Catostomus ardens*). Introduced brook trout (BKT; *Salvelinus fontinalis*) are also found in the watershed. The most abundant species captured during WGFD sampling efforts in Cliff Creek is SRC, but MWF, PSC, and MSC also occur there. There are also several amphibians associated with riparian habitat in the watershed, all of which are listed as "species of greatest conservation need" (WGFD 2005b). These include the blotched tiger salamander *(Ambystoma mavortium melanostictum)*, boreal toad (*Anaxyrus boreas boreas*), great basin spadefoot (*Spea intermontana*), American bullfrog (*Lithobates catesbeianus*), northern leopard frog (*Lithobates pipiens*), boreal chorus frog (*Pseudocris maculata*), and Columbia spotted frog (*Rana luteiventris*).

In the past, the focus of fishery management in the Hoback River basin was to enhance angling opportunities by stocking native and non-native trout. The current management objective is to maintain a wild population of SRC. Brook trout were stocked initially in 1933 and sporadically for several years after that. SRC stocking began in 1939 and continued annually through 2005. In addition to stocking the mainstem, stocking of BKT and SRC also occurred in several tributaries (Cliff, Dell, Fisherman, Granite, Shoal, and Willow creeks). Bonneville cutthroat trout (*Oncorhynchus clarki utah)* were stocked into Turquoise and Shoal Lakes and this is the only other known introduction in the drainage (Rhea and Gipson 2007). From 1999 to 2005 the number of SRC stocked in the Hoback River was reduced annually and Rhea and Gipson (2007) observed that stocking did not enhance the fishery and that reduced stocking efforts actually enhanced the wild SRC population. The stocking program in the Hoback River was eliminated in 2005.

Habitat preferences of target species, and their life stages, is an important component of instream flow studies since flow recommendations are based on maintaining sufficient habitat for target species to carry out life history functions (e.g., growth and reproduction). These habitat preferences are used to develop habitat suitability curves that are used in PHABSIM and River 2D models (described below). Most research on habitat use has focused on YSC (perhaps including SRC in some cases since the two are not always differentiated), but since SRC are genetically very similar, it is likely that they behave similarly in regards to habitat preferences and reproduction. Dey and Annear (2006) found that adult YSC in Trout Creek (tributary of the North Fork Shoshone River) were most commonly found in areas with depths of 1.15–1.60 ft and average column velocities of 0.36–1.91 ft/s. For juvenile YSC, these ranges were slightly different with depths of 1.0–1.5 ft and average column velocities of 0.38–1.65 ft/s (Dey and Annear 2006). Growth of adult and juvenile SRC is most important during the relatively short summer and early fall periods. Habitat for these life stages is also critical during winter to allow over-winter survival.

In addition to adults and juveniles, two other life stages evaluated for habitat availability are related to reproduction, spawning adults and fry. YSC generally spawn between March and August depending on local hydrology and water temperatures (believed to be triggered around 41 °F; Kiefling 1978, Varley and Gresswell 1988, De Rito 2005). The stream gradient observed in spawning areas is usually less than 3% (Varley and Gresswell 1988), but non-migratory fluvial populations have been documented in streams with a mean gradient of 6 percent (Meyer et al. 2003). Spawning activity for YSC in Wyoming has been observed during May and June in watersheds within the Big Horn River Basin in north central Wyoming (Greybull River, Shoshone River and their tributaries; Kent 1984, Dey and Annear 2002, Dey and Annear 2006). Elevation has an influence on the timing of spawning in YSC with stream segments located at higher elevations more likely to remain colder and cause both spawning and egg incubation to occur later in the summer. Dey and Annear (2003) found that spawning occurred into July in streams above approximately 8,000 ft in elevation (in the Greybull watershed) and extended recommendations for spawning flows through July 15 in such high elevation sites. The upper portion of the Cliff Creek watershed is above 8,000 ft, but both instream flow segments are well below this elevation so it is likely that spawning will have been complete by June 30 in most years (and start as early as April 15, depending on local hydrology). Dey and Annear (2006) observed too few spawning YSC (n=4) to develop habitat suitability curves for spawning YSC in Wyoming and did not search for fry. Spawning YSC habitat suitability data from a Snake River tributary in Idaho are presented in Thurow and King (1994); these researchers found that velocity preference was highest from 1.12 to 1.72 ft/sec and depth preference highest from 0.52 to 0.82 ft. Fry habitat data for Colorado River cutthroat in Wyoming (Bozek and Rahel 1992) were used in the absence of any data available for YSC or SRC; the velocity range which was most often used was less than 0.1 ft/sec and the depth range was 0.36 to 0.49 ft. Fry are most likely to be present during July, August, and September in the Hoback River watershed.

Instream Flow Segments

Two stream segments are proposed for instream flow water right filings in Cliff Creek (TABLE 2; FIGURE 4). The boundaries for individual segments were identified after considering land ownership, hydrology, and stream channel characteristics. Within each segment, instream flow recommendations were developed for individual life stages of SRC (fry, spawning, juvenile, and adult). Securing instream flow water rights on these stream segments will help ensure the future of SRC and other important fish species in Wyoming by protecting existing base flow conditions in priority against potential but presently unidentified future consumptive and diversionary demands. These water rights apply directly to the instream flow segments, but there may also be some level of indirect protection by virtue of the fact that any new water development upstream of the instream flow segment must ensure enough water reaches the upstream end of each instream flow segment when an instream flow right is in priority.

TABLE 2. Location and length of the proposed instream flow segments on Cliff Creek. Coordinates and elevations are provided for the downstream end of segments and are UTM Zone 12, NAD83 datum.

Segment	Description	Length (mi)	Easting	Northing	Elevation (ft)
Lower	Little Cliff Creek downstream to the confluence with the Hoback River	2.3	540999	4788736	6,370
Upper	Snag Creek downstream to Little Cliff Creek	6.2	539986	4785832	6,520

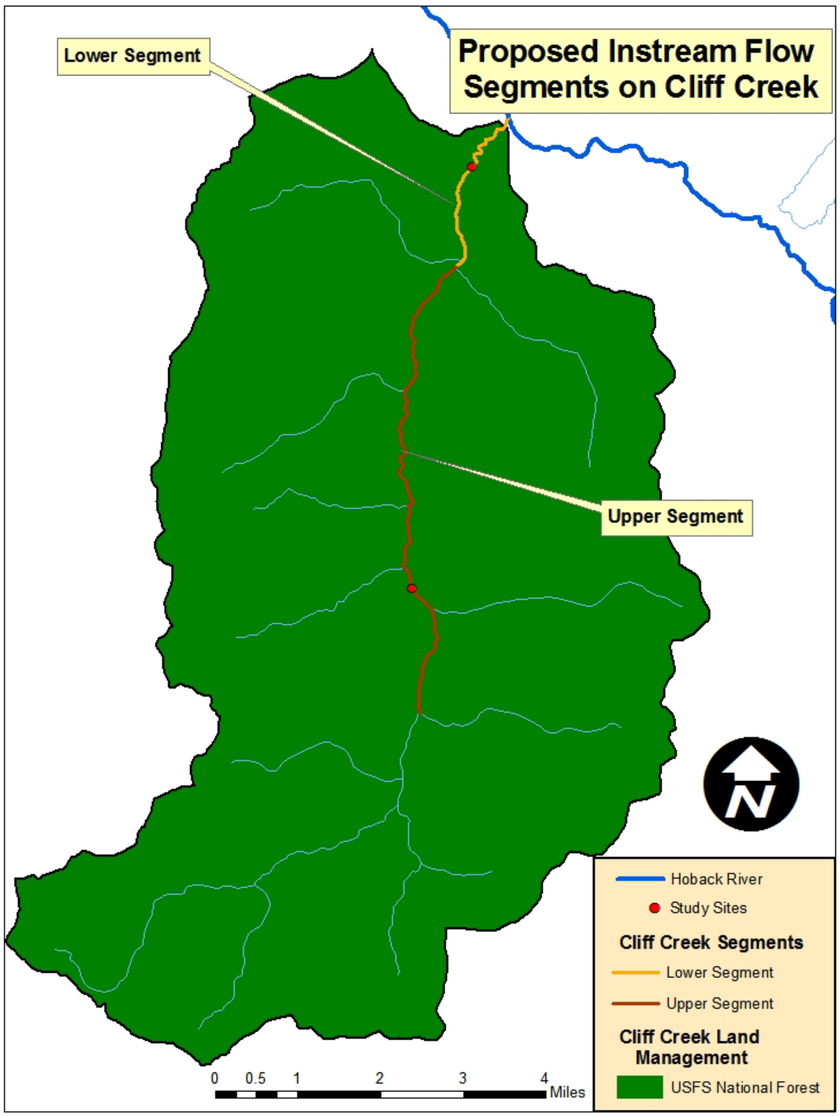

FIGURE 4. Two potential instream flow segments were identified on Cliff Creek and data were collected at two study sites to evaluate fish habitat.

Methods

Overall Approach for Developing Instream Flow Recommendations

A combination of several different methods was used to develop instream flow recommendations to maintain or improve the fishery in the Hoback River watershed. When possible, data were collected to run each of several habitat models for a study site (including the PHABSIM or River 2D habitat model, the Habitat Retention model, and the Habitat Quality Index model); however, the ecological characteristics and issues at a study site were sometimes unique and not necessarily appropriate for scaling up to the entire segment. As a consequence, though data may have been collected for all models at each site, the models used for developing a recommendation were selected based on their appropriateness for the characteristics and flow needs at each site. These models provide an evaluation of physical habitat for trout, thusflow recommendations based on these analyses were chosen to maintain sufficient habitat, which is defined as water depth, velocity, and cover necessary for each fish species and life stage of interest. Recommended flows were designed to protect habitat during portions of the year that are most critical to a given species and life stage. Recommendations were also evaluated relative to natural flow conditions, but because none of the instream flow segments had stream gage data, estimates of stream flow were developed for these comparisons.

One limitation of these flow recommendations is an underlying assumption that the physical habitat conditions and geomorphic processes in the stream are static. The analyses presented in this report indicate which flows provide suitable hydraulic habitat within this existing channel form, but the channel form may change over time. Channel form is a direct result of interactions among eight variables: discharge, sediment supply, sediment size, channel width, depth, velocity, slope, and roughness of channel materials (Leopold et al. 1964; Heede 1992; Leopold 1994). For many alluvial streams in their natural state, the channel exists in a state of dynamic equilibrium in which the sediment load is balanced with the stream's transport capacity over time (Bovee et al. 1998). When a stream is not in dynamic equilibrium, as associated with a lack of important high flow conditions, fine sediment buildup can occur causing, for example, a reduction in spawning habitat suitability. These higher, channel-maintenance flows are critical for maintaining long-term habitat availability for stream fish. These flows sustain the river channel conditions by permitting a connection to the floodplain, preventing buildup of fine sediments, and facilitating a variety of other important ecological processes (Carling 1995, Annear et al. 2004, Locke et al. 2008). Recommendations for flows sufficient to allow channel maintenance and provide a more complete flow pattern that fully maintains fishery habitat are presented in Appendix A. Should opportunities arise in the future to secure instream flow water rights for long-term maintenance of fluvial geomorphic processes in the Hoback River, Appendix A may provide a valuable reference.

Estimating Cliff Creek Hydrology

Development of flow recommendations for an instream flow study segment requires an understanding of local stream flow conditions. In many cases stream gage data is not available within the segment and the data must be estimated from a regional reference gage. That is the case for Cliff Creek since neither of the two proposed instream flow segments on Cliff Creek had sufficient localized stream gage data available (there was a USFS gage within the lower segment, but the data were not available for a long enough period). The reference gage used for all instream flow segments in the Hoback River watershed (HabiTech 2009) was the Little Granite

Creek USGS gage (13019438) with data available from late 1981 through 1992. To generate the necessary local flow estimates, an independent hydrologist (HabiTech, Inc., Laramie, WY) was contracted. HabiTech estimated mean annual flow (also called "average daily flow" or ADF), annual flow duration, monthly flow duration, and flood frequency for the proposed instream flow segments (HabiTech 2009). HabiTech calculated average daily flows from the contributing basin area models of Miselis et al. (1999) and Lowham (1988) and determined that neither accurately predicted flows at the reference gage. Alternative models using channel geometry (bankfull width) by Lowham (1988) and Miselis et al. (1999) yielded more accurate estimates of the reference gage with the former being the best. The bankfull width at the downstream end of each instream flow reach was used. A dimensional analysis approach was used to develop both annual and monthly flow duration information. Dimensionless duration tables were created for the reference gage by dividing each duration class by the mean annual flow (i.e., QW / QAA). The dimensionless flow value for each annual and monthly percentile was then multiplied by the estimated average annual flow for each instream flow segment to develop flow duration values for that segment. A similar approach was used to develop the flood frequency series. For further details, see HabiTech (2009).

Average daily flow estimates from the HabiTech (2009) report were used in applying the Habitat Quality Index and Habitat Retention models (described below). The 1.5-year return interval on the flood frequency series was used to estimate bankfull flow (Rosgen 1996) for use in the Habitat Retention model and for developing channel maintenance flow recommendations (Appendix A). Channel maintenance calculations also used the 25-year peak flow estimate from HabiTech (2009). The monthly flow duration series was used in developing winter flow recommendations. Throughout this report, the term "exceedance" is used, as in "20% exceedance flow." The 20% exceedance flow refers to the flow level that would be exceeded 20% of the time or that would be available approximately one year out of every five consecutive years.

Flow measurements collected by WGFD during instream flow habitat studies are included in the HabiTech (2009) report. These flow measurements were used to help validate the models and enhance the accuracy of the hydrological estimates by HabiTech (2009).

Predicting Fish Habitat Availability Using Instream Flow Models

The availability of fish habitat is evaluated using several different habitat models for each study site. "Habitat" in this report refers the combination of physical conditions (depth, velocity, substrate, and cover) for a given area. These physical conditions vary with discharge; however, they do not represent a complete account of all variables that comprise trout habitat. Habitat for trout also includes environmental elements such as water temperature, dissolved oxygen, distribution and abundance of prey and competitor species, movement timing and extent, and other variables. These other variables are important, but are not included in models used for these analyses because they do not fluctuate with changes in the quantity of flow as predictably as the physical habitat parameters. Interpretation of model results based on these physical habitat parameters assumes that this subset of trout habitat is important and provides a reasonable indication of habitat availability at each flow and an indirect expression of the ability of trout to persist on a short-term basis.

Physical Habitat Simulation Model

The Physical Habitat Simulation (PHABSIM) approach was used to estimate flows that will maintain habitat for individual life stages during critical time periods. The PHABSIM approach uses computer models to calculate a relative suitability index for target species like SRC based on depth, velocity, and substrate or cover (Bovee et al. 1998). Calculations are repeated at user-specified discharges to develop a relationship between suitable area (termed "weighted useable area" or WUA) and discharge. Model calibration data are collected across the stream at each of several locations (transects) and involve measuring depth and velocity at multiple locations (cells) along each transect. Measurements are repeated at three or more different discharge levels. By using depths and velocities measured at one flow level, the user calibrates a PHABSIM model to accurately predict the depths and velocities measured at the other discharge levels (Bovee and Milhous 1978, Milhous et al. 1984, Milhous et al. 1989).

Following calibration, the user simulates depths and velocities over a range of user-specified discharges. These predicted depths and velocities, along with substrate or cover information, are compared to habitat suitability curves (HSC). The relative value to fish of predicted depths, velocities, substrates, and cover elements are defined by HSCs which range between "0" (no suitability) and "1" (maximum suitability). At any particular discharge, a combined suitability for every cell is generated. That suitability is multiplied by the surface area of the cell and summed across all cells to yield weighted useable area for the discharge level. Results are often depicted by graphing WUA for a particular fish life stage versus a range of simulated discharges (Bovee et al. 1998). Relationships are best interpreted as a relative suitability index rather than a definitive prediction of physical area (Payne 2003).

River2D Model

The PHABSIM approach has been used extensively for modeling stream habitat and developing instream flow recommendations since its inception in the 1970s (Stalnaker et al. 1995, Bovee et al. 1998), however, two-dimensional models have received increasing attention and use (Ghanem et al. 1994, 1996, Bovee et al. 2008). These tools generate depth and velocity predictions throughout study reaches as opposed to the one-dimensional transect-based output that simulate physical habitat only in a longitudinal perspective. The end result of total area of useable habitat (WUA) is similar to PHABSIM, but the results are finer scaled and present a much more detailed characterization of habitat availability throughout the study site. The model is also able to predict conditions around complex habitats like multiple channels and eddies that are impossible or extremely complicated with a transect-based dataset. The two-dimensional model also generates habitat depictions that are more readily interpreted as to the spatial relationships of habitat availability. While PHABSIM was used in the upstream study site on Cliff Creek, the two-dimensional River2D model (Steffler and Blackburn 2002) was employed at a more complex study site in the downstream study segment.

One of the primary differences between PHABSIM and River2D models is that the latter entails development of a detailed map of elevation and substrate data of the stream channel bed and banks. The model uses the detailed elevation map and stage discharge relationship (developed at the downstream boundary) to move water through the site at a given discharge and allow estimates of depth and velocity at any location. All bed elevation points (northing, easting, and elevation) for the River2D model site were collected with a TopCon model 211D total station. Boulders were surveyed using a model where three points where recorded in the field (following the longest axis) and width and shape of the boulder recorded. These data on each boulder were put in the model and a series of points were generated that more accurately represented a boulder and these points were put into the River 2D elevation map. Substrate was mapped throughout the site using the categories vegetation, mud, silt, sand, gravel, cobble, boulder, and bedrock. The percentages of dominant and subdominant classes were assigned to each mapped area.

When a working model was developed from substrate, elevation, and discharge data, it required calibration to improve predictions of depth and velocity throughout the study site. This was done by attempting to match predicted water surface elevation throughout the site to data collected at each of several discharges. The primary tool for this calibration is adjusting roughness to minimize the average difference between the predicted and measured water surface elevations at several points throughout the study site. Adjustments were made to roughness values as needed to achieve the best possible model fit with the available data. When the model was calibrated at a given discharge it was then run at another calibration discharge and further modified until it worked well at both discharges. This process was repeated for all calibration discharges. A second calibration step involved comparing observed depths and velocities (collected at randomly spaced points) relative to predicted values at a calibration discharge and further, fine-scale, adjustments to roughness were made as needed to further refine the model fit. With each adjustment, all calibration discharges were re-run with the new roughness values to determine change to each.

The final result was a single calibrated model that was run at several discharges over the evaluation range. The calibrated model was used to simulate physical conditions in the study reach and estimate WUA for each SRC life stage at each discharge. The results are viewed in terms of the "peak" of habitat availability over the range of modeled discharges.

Habitat Retention Model

The Habitat Retention Method (Nehring 1979, Annear and Conder 1984) was used to identify the flow that maintains specified hydraulic criteria (TABLE 3) in riffles. Maintaining depth, velocity, and wetted perimeter criteria in riffles is based on an assumption that other habitat types like runs or pools remain viable for fish when adequate flows are provided in shallow riffles that serve as hydraulic controls (Nehring 1979). Flow recommendations derived from the Habitat Retention Method are intended to identify instream flows needed to maintain fish passage between habitat types and benthic invertebrate survival at any time of year when the recommended flow is naturally available. The flow identified by the Habitat Retention Method is important year round, except when higher instream flows are required to meet other fishery management purposes.

Simulation tools and calibration techniques used for hydraulic simulation in PHABSIM are also used with the Habitat Retention approach. The difference is that Habitat Retention does not translate depth and velocity information into conclusions about incremental changes in the amount of physical space suitable for trout life stages. The habitat retention method focuses on identifying riffle hydraulic characteristics that maintain fish passage and invertebrate production. The AVPERM model within the PHABSIM methodology is used to simulate cross section depth, wetted perimeter and velocity for a range of flows. The flow that maintains 2 out of 3 criteria (TABLE 3) for all three transects is then identified; however, because of the critical importance of depth for maintaining fish passage, the 0.2 ft threshold must be one of the criteria met for each transect.

TABLE 3. Hydraulic criteria for determining maintenance flow with the Habitat Retention method. These criteria vary with larger streams; for streams with a mean bankfull width greater than 20 ft the mean depth criteria is the product of 0.01 times mean bankfull width.

Category	Criteria
Mean Depth (ft)	0.20
Mean Velocity (ft/s)	1.00
Wetted Perimeter[a] (%)	50

a - Percent of bankfull wetted perimeter

Habitat Quality Index Model

The Habitat Quality Index (HQI; Binns and Eiserman 1979, Binns 1982) was used to determine relative trout habitat suitability or production potential over a range of late summer (July through September) flow conditions. Most of the annual trout production in Wyoming streams occurs during the late summer, following peak runoff, when longer days and warmer water temperatures facilitate growth. The HQI was developed by the WGFD to provide an index of relative habitat suitability, which is correlated to trout production as a function of nine biological, chemical, and physical trout habitat attributes. Each attribute is assigned a rating from 0 to 4 with higher ratings representing better trout habitat features. Attribute ratings are combined in the model with results expressed in trout Habitat Units (HU's), where one HU is defined as the amount of habitat that will support about 1 pound of trout, though the precise relationship can vary between streams. HQI results were used to identify the flow between July 1 and September 30 needed to maintain existing levels of adult and juvenile Yellowstone cutthroat trout production (habitat quality) and are based on an assumption that flow needs for other life stages are adequate at all other times of year. The model also assumes that water quality is not a limiting factor.

In the HQI analysis, habitat attributes measured at various flow events are assumed to be typical of late summer flow conditions. For example, stream widths measured in June under high flow conditions are considered an estimate of stream width that would occur if that flow level were a base flow occurring in September. Under this assumption, HU estimates are extrapolated through a range of potential late summer flows (Conder and Annear 1987). Some attribute ratings were mathematically derived to establish the relationship between discharge and trout habitat at discharges other than those measured. In calculating Habitat Units over a range of discharges, temperature, nitrate concentration, invertebrate numbers, and eroding banks were held constant.

Article 10, Section d of the Instream Flow statute states that waters used for providing instream flows “shall be the minimum flow necessary to maintain or improve existing fisheries”. The HQI is used to identify a flow to maintain the existing fishery in the following manner: the number of habitat units that occur under normal July through September flow conditions is quantified and then the flow that maintains that level of habitat is identified. The August 50% monthly exceedance flow was used as the reference standard of normal late summer flow levels and is consistent with how the HQI was developed (Binns and Eiserman 1979).

Natural Winter Flow

The four habitat modeling approaches described above are not as well suited to determine flow requirements during ice-prone times of year (October through early April). These methods were all developed for and apply primarily to open-water periods. Ice development during winter months can change the hydraulic properties of water flowing through some stream channels and compromise the utility of models developed for open water conditions. The complexities of variable icing patterns make direct modeling of winter trout habitat over a range of flows difficult if not impossible. For example, frazil and surface ice may form and break up on multiple occasions during the winter over widely ranging spatial and temporal scales. Even cases that can be modeled, for example a stable ice cap over a simple pool, may not yield a result worthy of the considerable time and expense necessary to calibrate an ice model. There are no widely accepted aquatic habitat models for quantifying instream flow needs for fish in under-ice conditions (Annear et al. 2004). As a result, a different approach was used to develop recommendations for winter flows.

For Wyoming Rocky Mountain headwater streams, a conservative approach is needed when addressing winter flow requirements. The scientific literature indicates that already harsh winter habitat conditions would become more limiting if winter water depletions were to occur. Even relatively minor flow reduction at this time of year can force trout to move more frequently, change the frequency and severity of ice formation, distribution and retention, and reduce the holding capacity of the few large pools often harboring a substantial proportion of the total trout population (Lindstrom and Hubert 2004). Hubert et al. (1997) observed that poor gage records often associated with the winter season requires use of a conservative value. The 50% monthly exceedance does not provide an appropriate estimate of naturally occurring winter flow. It is more appropriate from the standpoint of maintaining fisheries to recommend the higher flows of a 20% monthly exceedance. Such an approach assures that even in cases where flow availability is underestimated due to poor gage records or other estimation errors, flow approximating the natural winter condition will be recommended. This approach has been used for many recent instream flow recommendations (e.g., Dey and Annear 2006, Robertson and Dey 2008) and was adopted for the two instream flow segments on Cliff Creek.

Combining Methods to Arrive at Instream Flow Recommendations

Instream flow recommendations for Cliff Creek were developed for four seasonal periods, which are based on SRC biology and Hoback River hydrology (TABLE 4; FIGURE **5**). Over-winter survival is addressed with natural winter flow from October 1 through March 31. The hydrograph indicates that, on average, relatively low base flow conditions in winter persist through March 31 during both the highest and lowest flows recorded in the Hoback River. Habitat for juvenile and adult SRC is maintained for early spring connectivity prior to spawning during the rising limb of spring runoff from April 1 to April 30 with PHABSIM or River 2D habitat modeling. Spawning and incubation habitat for SRC is maintained from May 1–June 30 with habitat modeling results for the spawning lifestage using either PHABSIM or River 2D models. Summer habitat for growth and production is maintained from July 1–September 30 with Habitat Quality Index results (adult SRC habitat) and modeling results from either PHABSIM or River 2D for fry and juvenile SRC. The Hoback River hydrograph indicates that during low water years, there is little variation between flows in the early and late parts of this seasonal period (FIGURE **5**). When two or more methods could be used for a recommendation, the method chosen is the one that yields the higher flow needed for a particular fishery maintenance purpose. For example, the Habitat Retention approach provides a base flow which is usually too low to maintain sufficient habitat for all life stages and is not used for instream flow recommendations when other aspects of fishery maintenance require higher flows. When habitat is maximized at flows greater than the natural 20% exceedence flow, the latter is used as a maximum recommended instream flow. Channel maintenance flows perform their function during runoff in April, May, June, and July (Appendix A) but will not be used in the instream flow water right application as described in the Introduction.

Data Collection and Analysis

Lower Cliff Creek Segment

One study site (approximately 345 ft long) was selected to represent the lower Cliff Creek instream flow segment. The bankfull width in this reach was approximately 42 ft so the study site length was approximately 7 channel widths. The downstream end of the study site was approximately 0.9 miles upstream from the confluence with Hoback River (FIGURE 6). The upstream end of the study site was in a riffle and the downstream end of the site occurred in a run. An island bisects the stream into two channels in the middle of the site and creates complex habitat features including two large pools. The complexity of this site is representative of the range of habitat conditions available in the instream flow segment.

TABLE 4. Snake River cutthroat trout life stages and seasons considered in developing instream flow recommendations. Numbers indicate the method used for each combination of season and life stage, and light grey shading indicates the primary data used for flow recommendations in each season.

Life stage and Fishery Function	Over-Winter Survival Oct 1 – Mar 31	Early Spring Connectivity Apr 1 – Apr 30	Spring Spawning May 1 – Jun 30	Summer Production Jul 1 – Sep 30
Survival and movement of all life stages	1	2	2	2
Spawning and Incubation Habitat			3 or 4	
Fry Habitat				3 or 4
Juvenile Habitat	3 or 4	3 or 4	3 or 4	3 or 4
Adult Habitat	3 or 4	3 or 4	3 or 4	3 or 4
Adult Growth				5
All life stages habitat*		6	6	

1=Natural winter flow or Habitat Retention, whichever is greater, 2=Habitat Retention, 3=Physical Habitat Simulation, 4=River 2D Simulation, 5=Habitat Quality Index, 6=Channel Maintenance.
* Channel maintenance flow recommendations are presented in Appendix A.

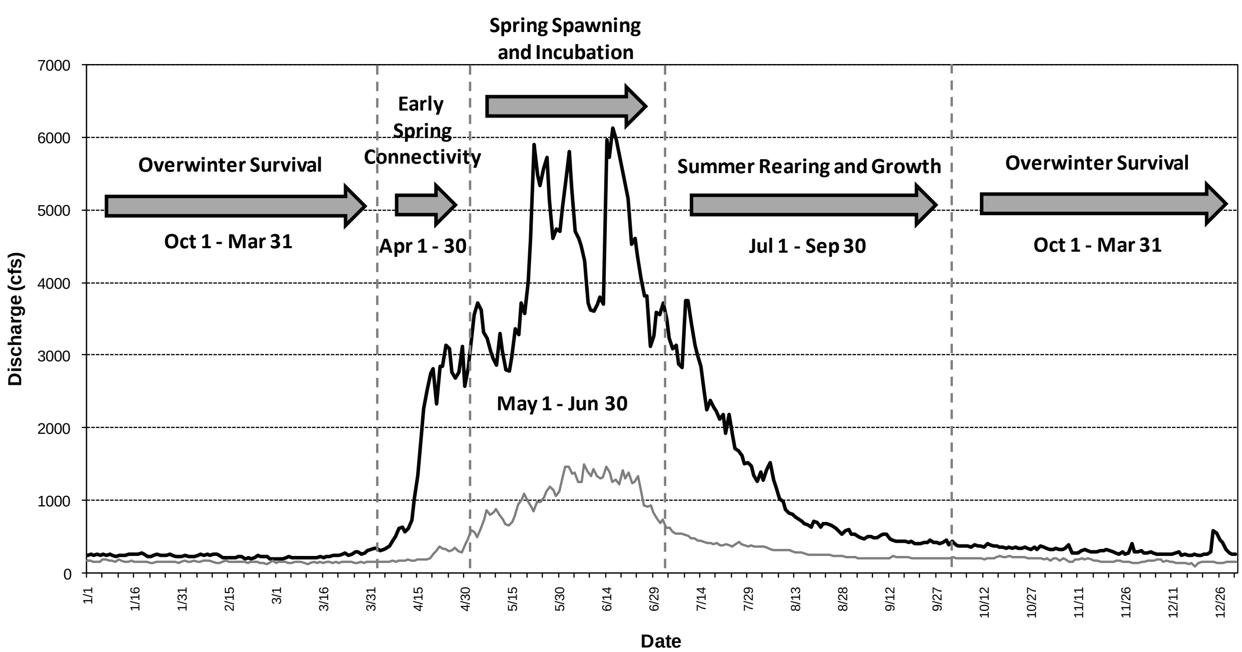

FIGURE 5. Lowest and Highest Daily Historical Discharge Values in Hoback R. and critical time periods for YSC. Data is from USGS gage 13019500 on the Hoback River (1944–1958).

FIGURE 6. Aerial image of lower Cliff Creek lower instream flow segment.

Upper Cliff Creek Segment

One study site (approximately 115 ft long) was selected to represent the upper Cliff Creek instream flow segment. The bankfull width in this reach was approximately 25 ft, so the study site length was 4–5 channel widths. The upstream end of the study site was approximately 1.7 miles downstream from the confluence with Snag Creek (FIGURE 7). The study site included the tail of a pool, a riffle section, and a run on the downstream end. Nine transects were placed as follows: three in riffles, four in runs, one in a pool and one in a glide. This site is representative of the habitat conditions available in the instream flow segment since much of the segment has poor pool development and is largely comprised of runs and riffles.

Data were collected in the upper Cliff Creek study site for PHABSIM modeling, an HQI assessment. The study site was visited four times in 2008 between June 8 and August 23 at discharges of approximately 80, 40, 17, and 13 cfs to measure habitat features under a wide range of flow conditions. Stage was measured during each visit at each of the nine PHABSIM transects and discharge was measured at two or more of those transects. All velocity measurements used in calculating discharge estimates were collected using a Marsh-McBirney Model 2000 flow meter set to integrate readings over a 25 second interval. Discharge estimation followed Rantz (1982). HQI data were collected during each of these visits.

Flows for Other Important Ecosystem Components

The models used to generate instream flow recommendations in the Hoback River watershed provide a good means of ensuring physical habitat availability for SRC, but do not address all aspects habitat with the resulting recommendations. An effective instream flow regime should also maintain diverse riparian and floodplain vegetation and provide suitable conditions for the community of animals that use these habitats. Channel maintenance flow recommendations as described in Appendix A would allow these kind of natural stream channel processes to occur and promote a healthy riparian assemblage of plants and animals (Stromberg and Patten 1990, Rood et al. 1995, Mahoney and Rood 1998).

Existing water quality conditions in the Hoback River watershed are excellent in and upstream of the instream flow segments. There are some issues with turbidity, particularly in watersheds that have unstable slopes, but water temperature, and various organic and inorganic constituents are believed to be at normal levels and relatively little anthropogenic pollution is apparent. Flow recommendations in this report are expected to maintain water quality within natural bounds and it is assumed that existing water quality features will remain within existing limits of natural variability. If drastic changes occur, then flow recommendations might need to be reviewed.

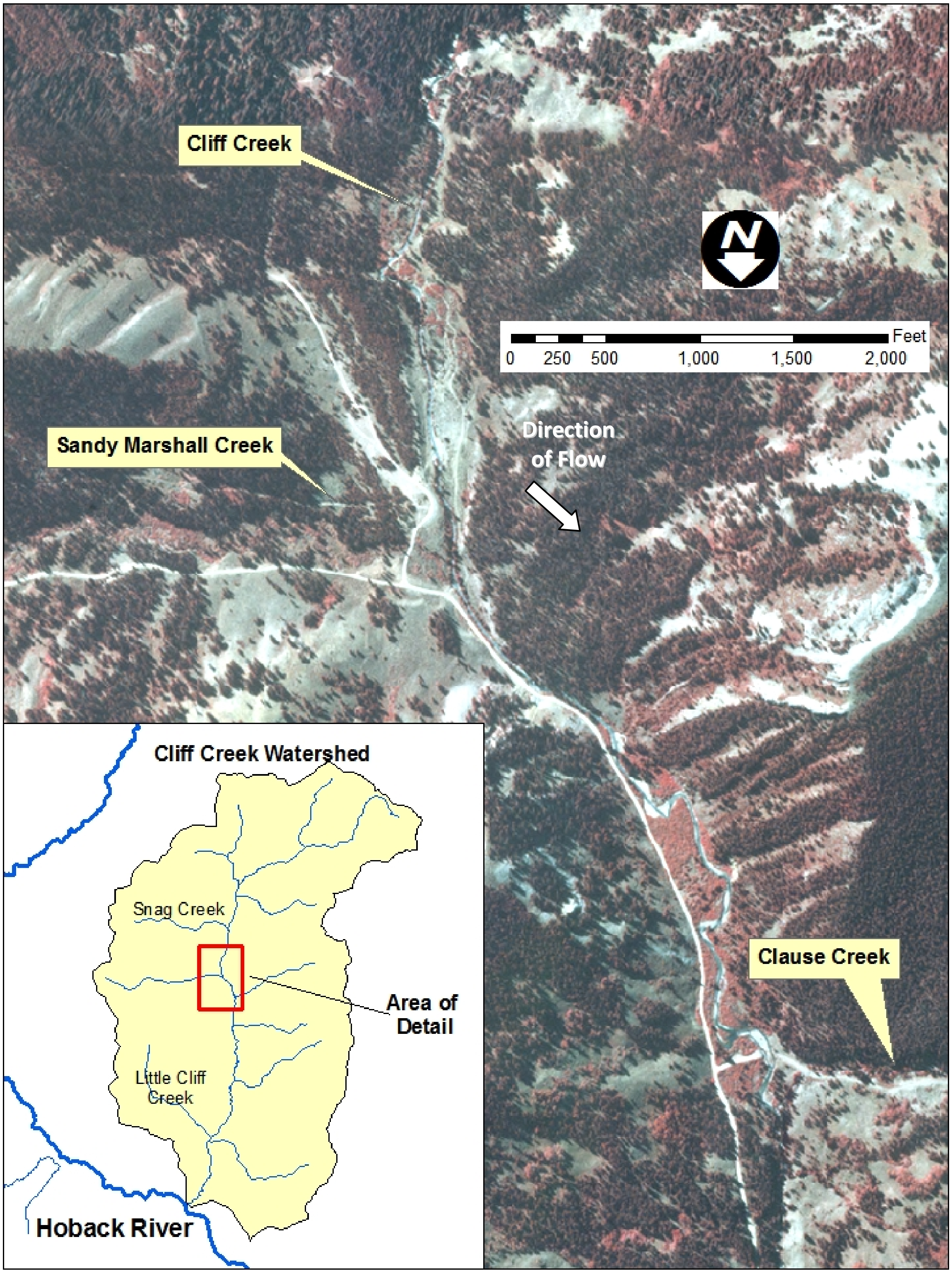

FIGURE 7. Aerial image of upper Cliff Creek upper instream flow segment.

RESULTS AND DISCUSSION

Lower Cliff Creek Segment

<u>Hydrology</u>

Since the USGS reference gage used for hydrology estimates (Little Granite Creek gage) was not functional in 2008, another gage was used for roughly comparing the mean discharge in the Hoback River watershed during the study period (2008) with the reference period (1981–1992). The reference gage is in the Snake River just upstream from Alpine, WY (site 13022500; this is the nearest gage downstream from the Hoback watershed). The mean daily discharge that occurred at the Alpine gage during July, August, and September in 2008 (6646 cfs) was higher than 8 of the 12 years in the reference period. This mean discharge value was substantially higher than during the three previous years (3940, 4143, and 5087 cfs).

Mean annual flow and select flood frequency and monthly flow duration were estimated for the lower Cliff Creek instream flow segment (TABLE 5; TABLE 6). HabiTech (2009) noted that WGFD discharge measurements collected in the segment were within expectations of their estimates and concluded that their approach yielded reasonable results. Due to the higher than average flow conditions in 2008 compared with the reference period (1981–1992), the five discharges measured by WGFD in 2008 (TABLE 7) were greater than the estimated 50% monthly exceedance flows.

In addition to monthly exceedence values as an indicator of flow conditions in the segment, HabiTech (2009) also produced daily flow estimates for five years (the period of record was first divided to represent wet, moderately wet, average, moderately dry, and dry conditions, then a representative year randomly selected from each group). Stream gage data from the same randomly selected five years were used to prepare daily flow estimates for both Cliff Creek segments. Because of this and the fact that estimates for all segments are based on data from the same reference gage, the five representative hydrographs follow the same pattern for both segments with the difference being that the curve migrates up or down on the y-axis in proportion to the contributing basin area upstream of each segment (FIGURE 8). These hydrographs provide an indication of the range of discharge conditions that may occur in each instream flow segment. However, in reality there is considerable variation in the timing and pattern of flow within a given year and between different years that is not fully described by five individual hydrographs simulated by HabiTech (2009). As a consequence these should be viewed only as a general template of runoff patterns.

TABLE 5. Estimated hydrologic characteristics for the lower Cliff Creek instream flow segment (HabiTech 2009).

Flow Parameter	Estimated Flow (cfs)
Mean Annual	70
1.5-year peak	498
25-year peak	2461

TABLE 6. Estimated monthly exceedence values for the lower Cliff Creek instream flow segment (HabiTech 2009).

Month	**50% Exceedence (cfs)**	**20% Exceedence (cfs)**
October	17	27
November	16	22
December	13	18
January	12	15
February	12	15
March	16	21
April	67	135
May	206	399
June	215	447
July	68	117
August	35	50
September	21	33

TABLE 7. Dates of collection and discharge measurements collected in the lower Cliff Creek instream flow segment in 2008.

Date	**Discharge (cfs)**
July 9	149
July 17	92
August 13	45
August 22	42
September 23	31

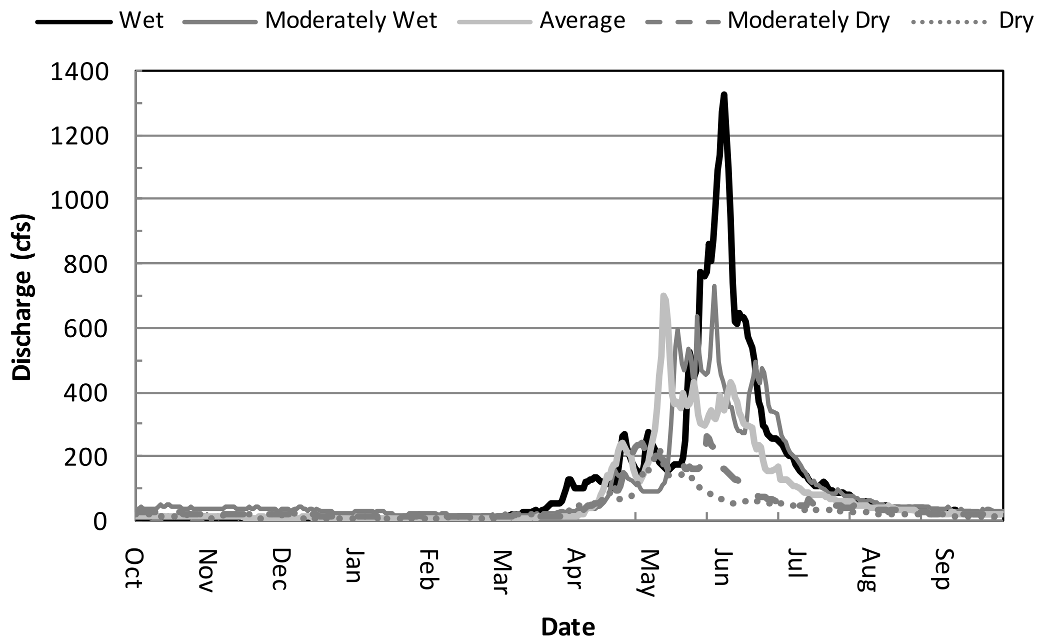

FIGURE 8. Simulated annual hydrographs for wet, moderately wet, dry, moderately dry, and average conditions for the lower Cliff Creek instream flow segment (HabiTech 2009).

<u>River2D Model</u>

A River 2D model was created from bathymetry data collected at the field site and initially calibrated at a discharge of 42.5 cfs. Calibration was accomplished by adjusting model inputs to closely match field observations of stage (water surface elevation) and velocity. Model inputs include discharge, water surface elevation (at the downstream end of the study site), and a channel roughness factor for each node in the underlying model mesh. To calibrate, the discharge (42.5 cfs) and observed stage were input with the initial roughness values and the predicted water surface elevation was compared to the observed elevation at several points along the study site. To improve predicted elevation values from the model, initial roughness values were adjusted up (to raise predicted water surface elevation) or down (to lower the elevation) in locations where there was error. These adjustments improved the model predictions, but a perfect fit was never achieved. With several adjustments the model was improved such that all water surface elevation points (n=68) were within 2 in and the majority (n=49) were within 0.8 in of the observed value (FIGURE 9). After calibrating to the 42.5 cfs discharge, the model was then run at 92.5 cfs for additional calibration efforts and finally at 157.1 cfs. The model predictions for the latter two discharges were not as accurate however all points were within 2.4 in and the majority within 1.6 in of observed conditions.

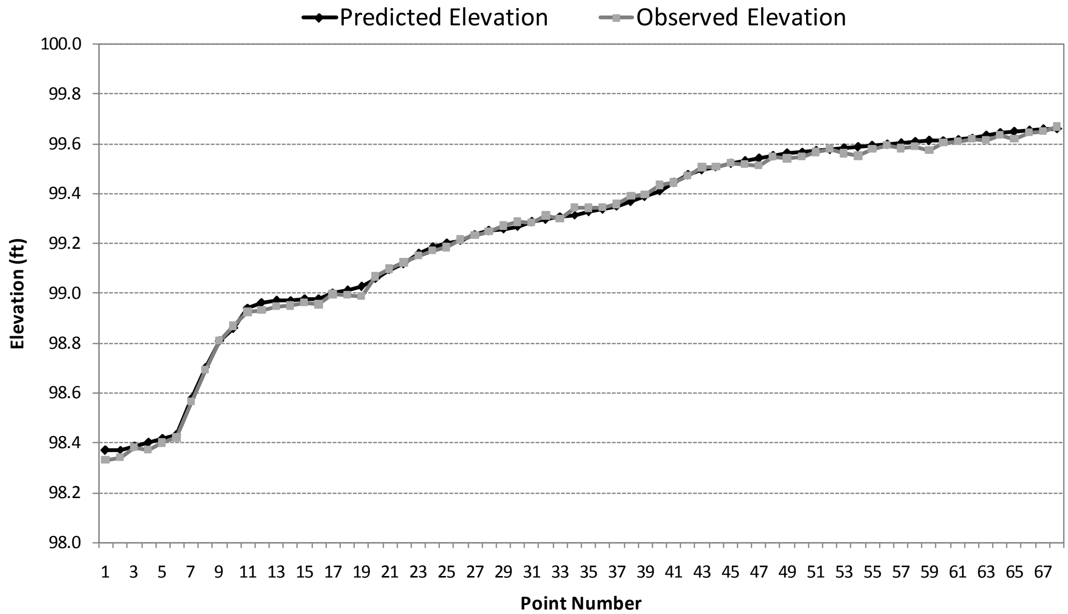

FIGURE 9. Final model-predicted and observed water surface elevations at 42.1 cfs along the right bank (looking downstream) in the lower Cliff Creek study site.

Velocity calibration was accomplished by comparing modeled and observed velocities across a single cross-section (at the upper end of the model) at three discharges (42.1, 86.4, and 148.9 cfs). At 42.1 cfs, data from two additional cross-sections (on the two channels split by the island) were also used. In each case slight adjustments to roughness were made to improve model fit and the results for water surface elevations reviewed. Because data were collected for cross-sections, it was possible to match the pattern of velocity across the channel rather than focus on individual measurements (FIGURE 10). The final patterns matched closely despite errors in individual measurements of up to 1.7 ft per second over the three calibration discharges.

Once the River 2D model was calibrated, simulations were conducted for the study site over a range of flows between 15 cfs and 800 cfs. This range of flow modeling included the predicted 20% exceedence flow for January and February to well over bankfull flow (498 cfs; HabiTech 2009). Five cfs increments were simulated up to 100 cfs and the increments became larger with increasing discharge. At each flow, the calibrated River 2D model predicted depth and velocity (and other values such as Froude number and shear velocity magnitude) at all nodes on the mesh and interpolated values between nodes. These data, combined with the substrate conditions, allow predictions of available habitat for the species/life stages of interest.

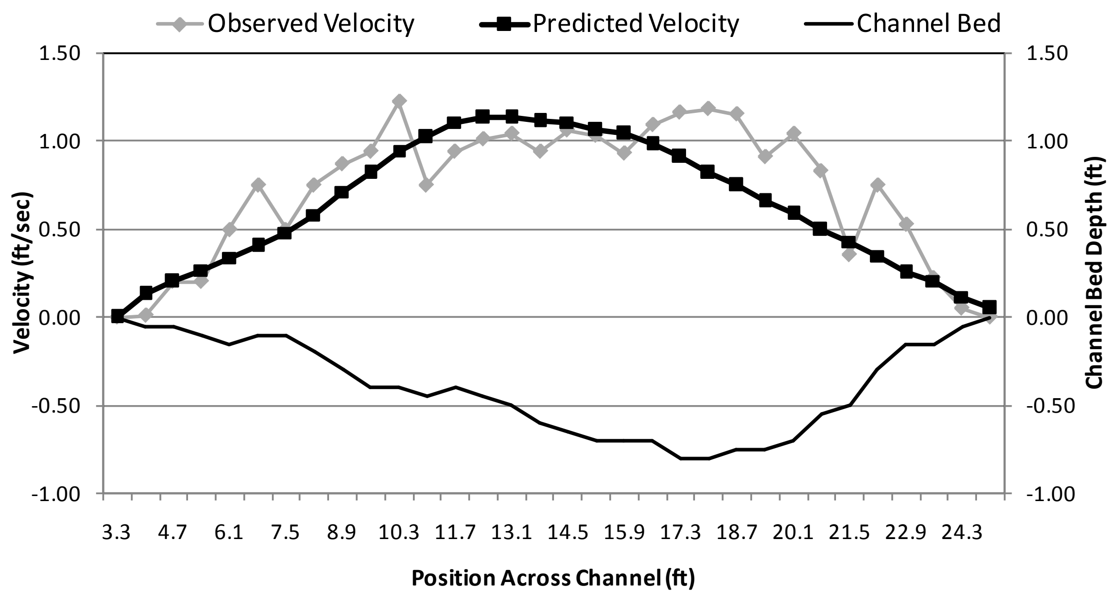

FIGURE 10. Final model-predicted and observed velocities at 42.1 cfs along the upstream cross-section in the lower Cliff Creek study site.

Habitat suitability curves representing the four life stages (fry, juvenile, adult, and spawning) of SRC were used to interpret the hydraulic conditions predicted at each flow by the River 2D model. Depth, velocity, and substrate data were used to estimate a combined suitability value for each life stage in all areas in the study site. Each area was multiplied by the combined suitability value to generate a weighted usable area (WUA) for the entire study site for a given life stage and discharge.

A review of change in WUA over the range of flows reveals discharge values that provide the amount of physical habitat at each specified flow. For SRC fry, the peak in habitat suitability occurs at 80 cfs (FIGURE 11). In this discharge range, the flow remains within the active channel (well below bankfull flow) and all suitable habitat for fry occurs along the margins of the channel (FIGURE 12). At 80 cfs, some habitat appears to occur in small isolated pools in the downstream portion of the reach that the model suggests would be connected at a slightly higher flow. The percent of maximum WUA is also fairly high (>80%) at the lowest modeled discharge (15 cfs). Least favorable conditions for habitat availability occur in the range of 30–50 cfs.

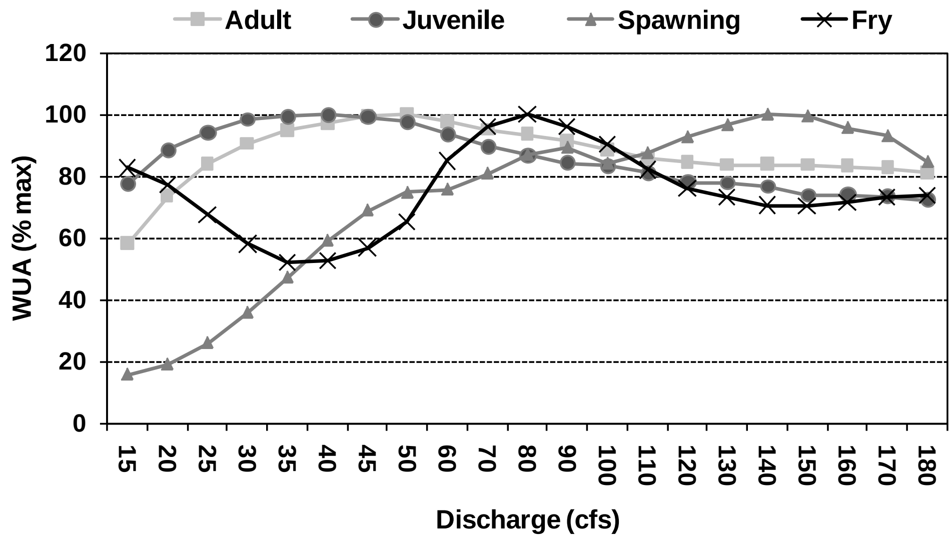

FIGURE 11. Relationship between weighted usable area and discharge for all life stages in the lower Cliff Creek study site.

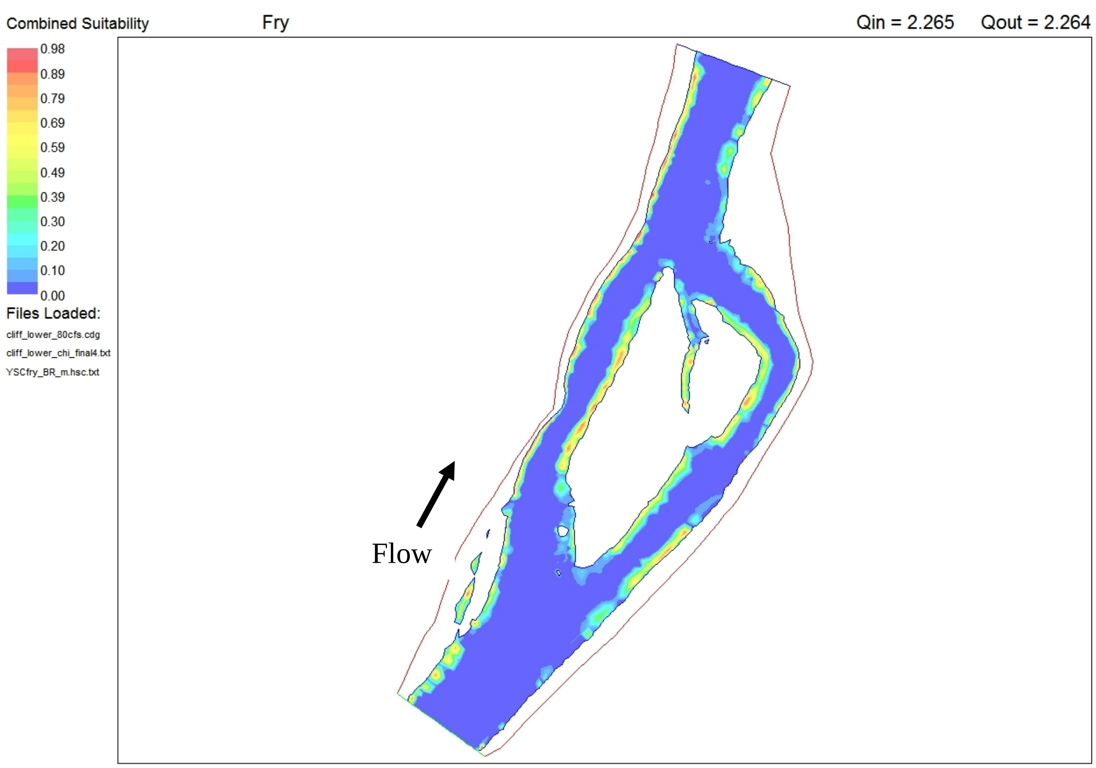

FIGURE 12. Combined suitability for SRC fry in the lower Cliff Creek study site at 80 cfs discharge.

For juvenile SRC, habitat suitability is maximized at 40 cfs (FIGURE 11). Unlike fry habitat conditions, habitat availability for juvenile SRC is lowest at 15 cfs discharge, increases with increasing discharge to the peak condition, and then declines with increasing discharge. Suitable habitat occurs primarily in the two pools and an area at the head of the smaller side channel near the island (FIGURE 13).

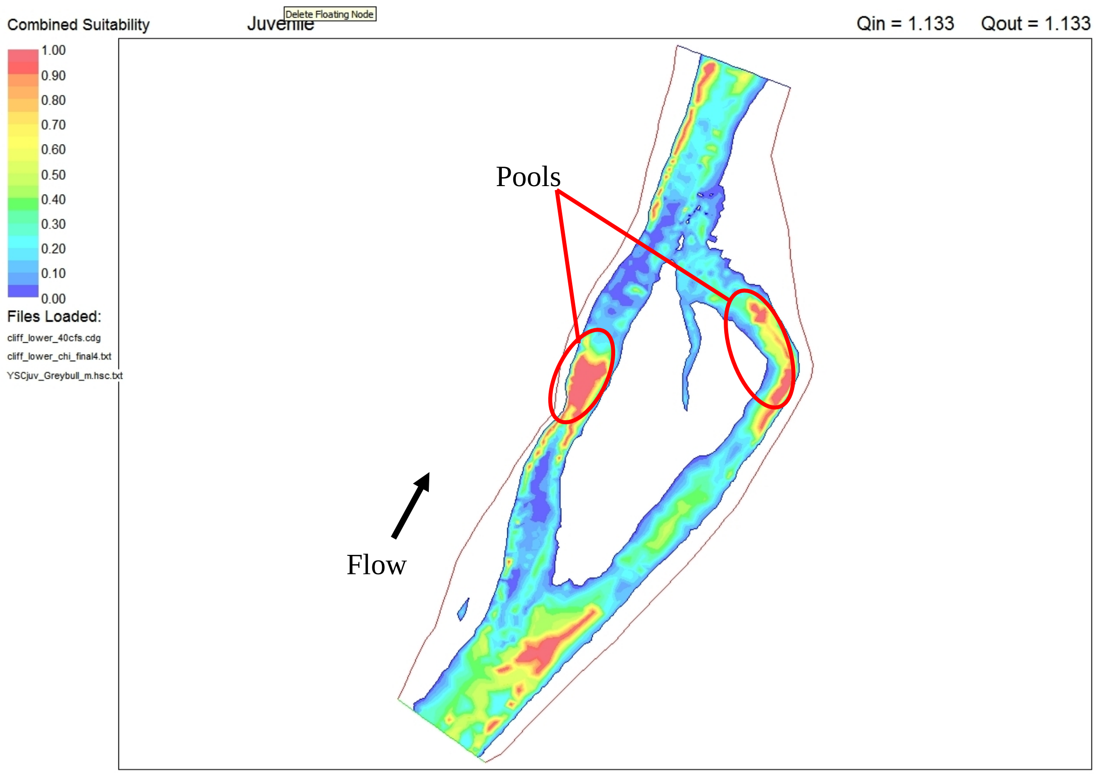

FIGURE 13. Combined suitability for juvenile SRC in the lower Cliff Creek study site at 40 cfs discharge.

For adult SRC, habitat availability is maximized at 50 cfs (FIGURE 11). Similar to juvenile habitat conditions, habitat suitability for adult SRC increases slowly with discharge to the peak condition and then declines slowly with greater discharge. Suitable habitat for adult SRC occurs in nearly the same areas as for juvenile SRC, but with even more concentration in pool habitats (FIGURE 14).

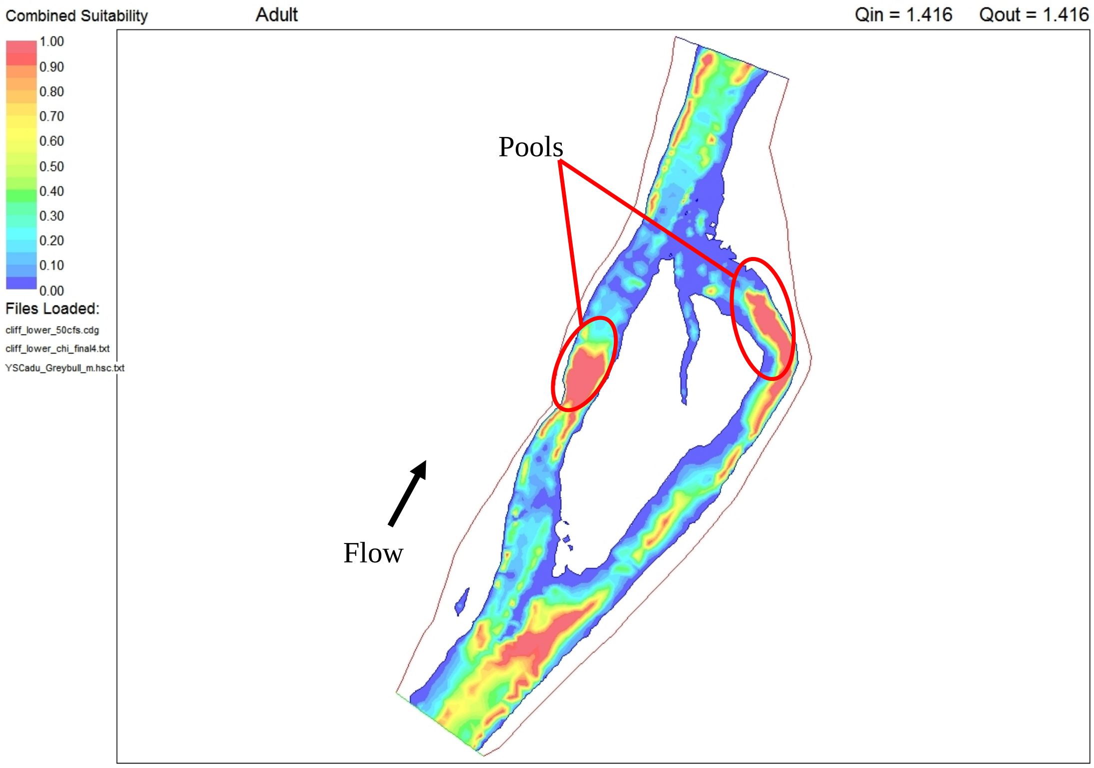

FIGURE 14. Combined suitability for adult SRC in the lower Cliff Creek study site at 50 cfs discharge.

For spawning SRC, habitat suitability is maximized at 140 cfs (FIGURE 11). Though spawning habitat does not comprise a substantial area in the study site (FIGURE 15), there are several distinct locations and many more important spawning areas in the instream flow segment. It is important to maintain flows for spawning in this reach. One of the primary limitations to spawning is often the availability of suitable-sized substrate, but this study site and the entire segment has suitable substrate over a large portion of the total area (FIGURE 16). Depth and velocity conditions are also suitable over a large portion of the site, but only a few locations have suitable conditions for all three variables. The 50% exceedence flows for May and June are estimated at 206 and 215 cfs, respectively, so the 140 cfs flow that maximizes habitat suitability for spawning should occur frequently during this period.

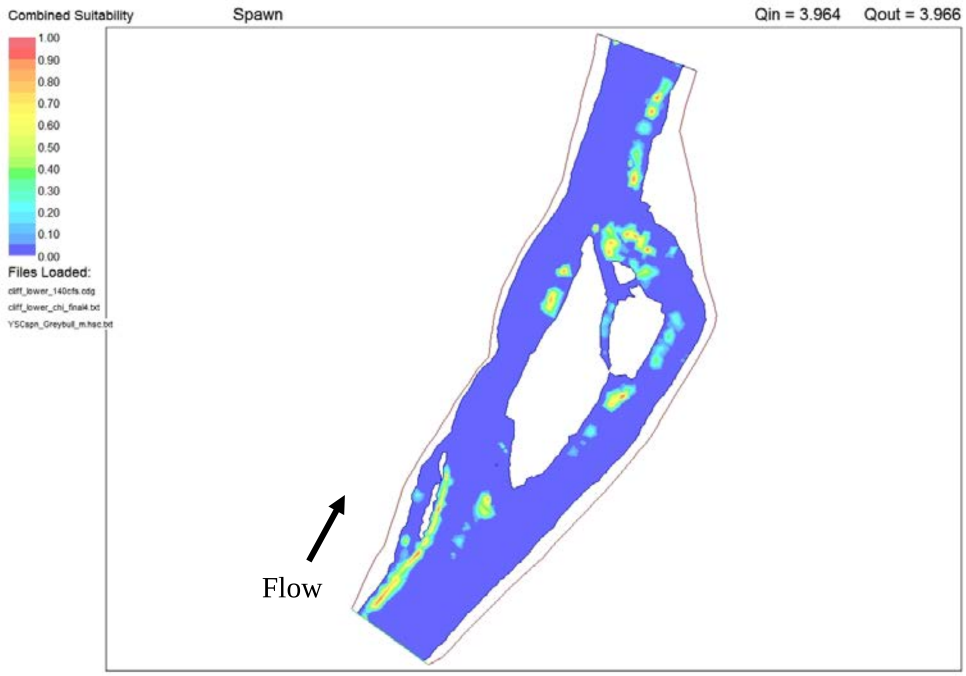

FIGURE 15. Combined suitability for spawning SRC in the lower Cliff Creek study site at 140 cfs discharge.

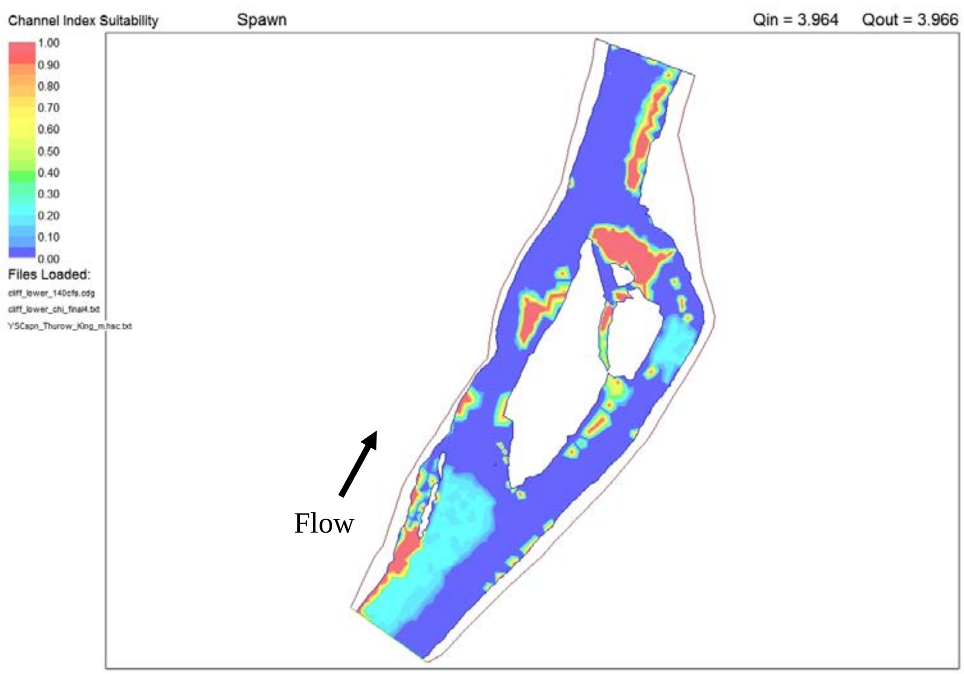

FIGURE 16. Suitability of substrate for spawning SRC in the lower Cliff Creek study site at 140 cfs discharge.

Habitat Retention Model Calibration and Simulation

The habitat retention model was used to evaluate hydraulic characteristics that affect the survival and movement of all life stages over a range of discharges in the Cliff-Lower instream flow segment. With this model the hydraulic characteristics of at least three riffle transects are estimated and evaluated to determine the discharge that maintains fish passage (connectivity) between habitat types and provides sufficient depth, velocity, and wetted area to ensure survival of fish prey items (benthic invertebrates).

TABLE 8. Estimated hydraulic conditions for three riffles over a range of modeled discharges in the lower Cliff Creek instream flow segment. Bold indicates that the hydraulic criterion was met for an individual attribute; the grayed-out discharge value meets the selection criteria.

Riffle Transect Number	Discharge (cfs)	Mean Velocity (ft/sec)	Mean Depth (ft)	Wetted Perimeter (% of bankfull)
1	300.0	5.2	1.35	1.02
	200.0	4.2	1.13	0.98
	100.0	2.8	0.90	0.92
	60.0	2.1	0.75	0.88
	25.0	1.4	0.49	0.85
	15.0	**1.1**	**0.39**	0.82
	10.0	0.9	0.34	0.77
	5.0	0.7	0.25	**0.69**
2	300.0	4.9	1.43	1.00
	200.0	3.9	1.19	0.98
	100.0	2.7	0.97	0.94
	60.0	2.1	0.77	0.91
	25.0	1.4	0.55	0.82
	15.0	**1.1**	0.50	0.70
	10.0	0.9	**0.41**	0.67
	5.0	0.6	0.29	**0.62**
3	300.0	5.3	1.13	0.98
	200.0	4.2	0.95	0.96
	100.0	2.8	0.81	0.86
	60.0	2.1	**0.68**	0.81
	25.0	1.3	0.48	0.75
	15.0	**1.0**	0.39	0.73
	10.0	0.9	0.32	0.69
	5.0	0.6	0.30	**0.52**

The three hydraulic variables evaluated with this model are mean velocity, mean depth, and the wetted perimeter (as a percentage of bankfull width). The lowest discharge at which two of the three criteria are maintained at all three riffles (TABLE 8) is the recommended discharge to maintain habitat throughout the instream flow segment. All three riffle cross-sections used for this analysis had similar hydraulic attributes. Bankfull discharge is approximately 500 cfs in this reach and at that flow riffles 1 and 2 result in a stream width of 42.2 and 42.5 ft; riffle 3 was much wider at 68.8 ft. Despite the differences in width, mean water velocity is predicted to decline to approximately 1.0 ft/sec when discharge declines to 15 cfs on all three cross-sections. These riffles have relatively steep banks and wetted perimeter remains greater than 50% of the bankfull width down to very low discharge in each. The mean depth was the most variable among riffles; the threshold value for this variable (0.01 * mean bankfull width) was crossed at approximately 15 cfs on riffle 1, 11 cfs on riffle 2, and 60 cfs on the wider riffle 3.

The final result of this analysis is that 15 cfs maintains two of the three hydraulic criteria at all three riffles. This flow will maintain base level conditions for fish passage and to provide habitat for benthic invertebrate populations on these riffles.

<u>Habitat Quality Index Model</u>

The HQI model data (FIGURE 17) was important in evaluating late summer habitat production potential for this instream flow segment. The 50% exceedence flow value for August (35 cfs; TABLE 5) is used as a reasonable estimate of normal late summer flow levels for this model. At this flow, the stream provides 107.6 Habitat Units, which is the lowest flow that would provide that amount of habitat. Decreasing discharge to 30 cfs would decrease the number of Habitat Units by at least 17%. Typically, as flow declines in streams, water temperature in late summer tends to increase. We held maximum summer temperature constant when running this model but know that increased temperature at lower flows would decrease Habitat Units by more than 17%. Therefore, the instream flow recommendation to maintain adult YSC habitat during the late summer period is 35 cfs.

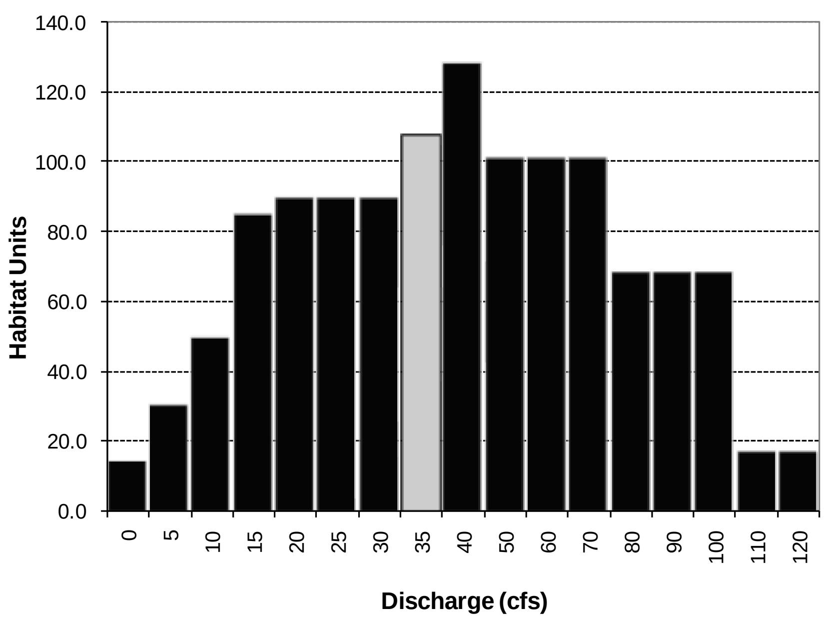

FIGURE 17. Habitat Quality Index vs. discharge in the lower Cliff Creek instream flow segment. X-axis flows are scaled to show where changes in Habitat Units occur. The recommended flow is indicated by the light shaded bar.

Instream Flow Recommendations

A table with instream flow recommendations for all segments (TABLE 12) is included in the section titled "Summary of Instream Flow Recommendations." Recommendations are provided for specific seasonal fishery needs for the lower Cliff Creek instream flow segment:

- Natural winter flows of up to 15 cfs are recommended for October 1–March 31 to maintain over-winter survival of all life stages of SRC at existing levels. This is the lowest estimated value for the 20% monthly exceedence discharge for any month during that time period (the range is 15–27 cfs) and also equal to the discharge recommendation of the habitat retention model.
- During the early spring period (April 1–30) a discharge of up to 45 cfs is recommended (based on River 2D results) to maintain existing SRC juvenile and adult habitat and longitudinal connectivity within the instream flow segment. Connectivity between habitats is particularly important during this time period as SRC move to spawning areas and prepare to spawn.
- The SRC spawning period (May 1–June 30) recommendation is for discharge up to 140 cfs based on peak spawning habitat availability for SRC (River 2D results). This level of flow will maintain existing habitat for this life history need.
- The summer (July 1–September 30) recommendation is 35 cfs based on the HQI results that maintain existing habitat conditions for growth and production of adult SRC. Fry habitat would be maximized at 80 cfs, but discharge of that magnitude is uncommon in this time period. The recommended flow will maintain existing habitat for fry.

Upper Cliff Creek Segment

Hydrology

As discussed in the section on the lower Cliff Creek instream flow segment, the discharges that occurred in the Hoback River basin during 2008 were generally higher than during the reference period. TABLE 9 and TABLE 10 list estimated mean annual flow and select flood frequency and monthly flow duration estimates for the upper Cliff Creek instream flow segment. HabiTech (2009) noted that WGFD discharge measurements collected in the segment were within expectations of their estimates and concluded that their approach yielded reasonably accurate results. Due to the higher flow conditions relative to historical averages, the discharges measured by WGFD in 2008 (TABLE 11) were greater than the estimated 50% monthly exceedance flows.

TABLE 9. Estimated hydrologic characteristics for the upper Cliff Creek instream flow segment (HabiTech 2009).

Flow Parameter	Estimated Flow (cfs)
Mean Annual	49
1.5-year peak	349
25-year peak	1722

TABLE 10. Estimated monthly exceedence values for the upper Cliff Creek instream flow segment (HabiTech 2009).

Month	50% Exceedence (cfs)	20% Exceedence (cfs)
October	12	19
November	11	15
December	9	13
January	8	11
February	8	11
March	11	15
April	47	94
May	144	279
June	151	313
July	47	82
August	24	35
September	15	23

TABLE 11. Dates of collection and discharge measurements collected in the upper Cliff Creek instream flow segment in 2008.

Date	**Discharge (cfs)**
July 8	80
July 18	40
August 13	17
August 23	13
September 25	10

In addition to monthly exceedence values as an indicator of flow conditions in the segment, HabiTech (2009) also produced daily flow estimates for five years (the period of record was first divided to represent wet, moderately wet, average, moderately dry, and dry conditions, then a representative year randomly selected from each group). Stream gage data from the same randomly selected five years were used to prepare daily flow estimates for both Cliff Creek segments. Because of this, and the fact that estimates for all segments are based on data from the same reference gage, the five representative hydrographs follow the same pattern for both segments with the difference being that the curve migrates up or down on the y-axis in proportion to the contributing basin area upstream of each segment (FIGURE 18). These hydrographs provide an indication of the range of discharge conditions that may occur in each instream flow segment. However, there is considerable variation in the timing and pattern of flow within a given year and between different years that is not fully described by five individual hydrographs simulated by HabiTech (2009). As a consequence these should be viewed only as a general template of runoff patterns.

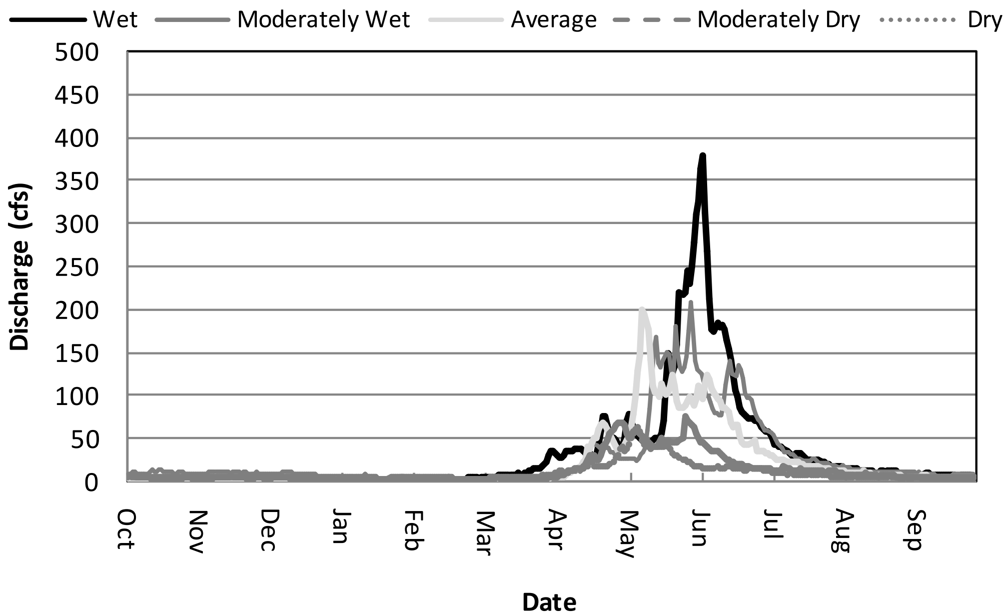

FIGURE 18. Simulated annual hydrographs for wet, moderately wet, dry, moderately dry, and average conditions for the upper Cliff Creek instream flow segment (HabiTech 2009).

Physical Habitat Simulation Model

The PHABSIM model was used to model habitat for all life stages of SRC in the upper Cliff study site (FIGURE 19). Simulations were conducted through the study site using a calibrated PHABSIM model over the flow range 5 cfs to 200 cfs. The model was run at each flow increment using data from all nine transects combined. The transects were evaluated as part of a continuous study area (dependent upon one another) and each weighted according to the length of the habitat feature represented by that transect. When the calibrated model was run for a given species / life stage at a given discharge, the resulting weighted usable area (WUA) was the final output used for interpretation.

A review of change in WUA over the range of flows reveals discharge values that provide the amount of physical habitat at each flow. For SRC fry, the peak in habitat suitability occurs at 20 cfs (FIGURE 19). In this discharge range, the flow remains within the active channel (well below bankfull flow) and all suitable habitat for fry occurs along the margins of the channel. The peak in habitat suitability for juvenile SRC also occurred at 20 cfs. Adult SRC habitat is most suitable at 30–35 cfs. Finally, the model indicated that spawning habitat is maximized at 20 cfs.

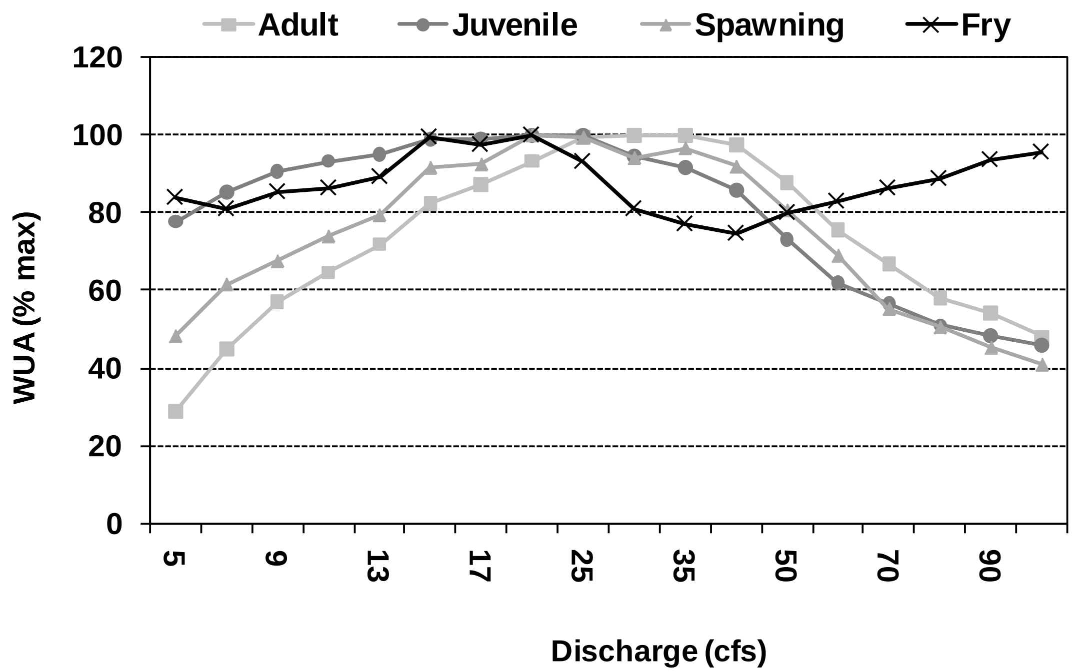

FIGURE 19. Relationship between weighted usable area and discharge for all life stages in the upper Cliff Creek study site.

Habitat Quality Index Model

The HQI model data (FIGURE 20) was important in evaluating late summer trout habitat production potential for this instream flow segment. The 50% exceedence flow value for August (24 cfs; TABLE 10) is used as an estimate of typical late summer flow levels for this model. At this flow, the stream provides 27.8 Habitat Units; 17 cfs is the lowest flow that would provide the same number of habitat units. Typically, as flow declines in streams, water temperature in late summer tends to increase. We held maximum summer temperature constant when running this model but know that increased temperature at lower flows would decrease Habitat Units by more than is shown in this analysis. Therefore, the instream flow recommendation to maintain existing adult SRC production potential during the late summer period is 17 cfs.

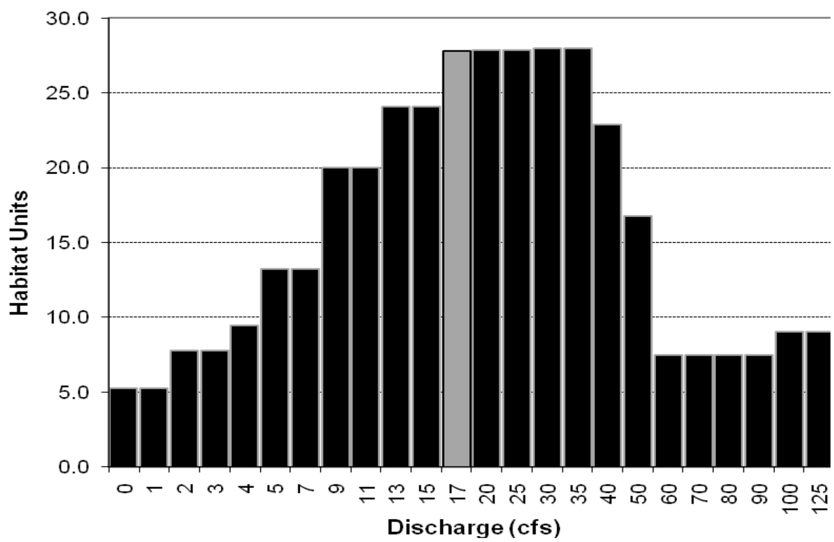

FIGURE 20. Habitat Quality Index vs. discharge in the upper Cliff Creek instream flow segment. X-axis flows are scaled to show where changes in Habitat Units occur. The recommended flow is indicated by the light shaded bar.

Instream Flow Recommendations

A table with instream flow recommendations for all segments (TABLE 12) is included in the section titled "Summary of Instream Flow Recommendations." Recommendations are provided for specific seasonal fishery needs for the upper Cliff Creek instream flow segment:

- Natural winter flows of up to 11 cfs are recommended for October 1–March 31 to maintain existing rates of over-winter survival for all life stages of SRC. This is the lowest estimated value for the 20% monthly exceedence discharge for any month during that time period (the range is 11–19 cfs).
- During the early spring period (April 1–30) a discharge of up to 20 cfs is recommended (based on River 2D results) to maintain SRC juvenile and adult habitat and longitudinal connectivity within the instream flow segment. Connectivity between habitats is particularly important during this time period as SRC move to spawning areas and prepare to spawn.
- The SRC spawning period (May 1–June 30) recommendation is for discharge up to 20 cfs based on peak spawning habitat suitability for SRC (River 2D results). This level of flow will maintain or improve existing levels of SRC spawning success.
- The summer (July 1–September 30) recommendation is 17 cfs based on the HQI results that maintain existing habitat conditions for growth and production of adult SRC. Fry habitat is also maximized at this discharge and will maintain existing levels of habitat for this life stage.

SUMMARY OF INSTREAM FLOW RECOMMENDATIONS

Cliff Creek provides important SRC habitat for ensuring their long-term persistence in the state and a wild SRC fishery is currently the fishery management focus for the entire Hoback River watershed. A reconnaissance of the stream revealed that instream flow water rights in two segments were appropriate for maintaining habitat for and populations of SRC in this stream. If approved by the State Engineer, the two proposed instream flow water right filings in Cliff Creek will protect existing base flow conditions when they are naturally available against presently unknown future out-of-channel uses up to the limit of recommended water rights for each segment described in this report. Approximately 8.5 miles of stream habitat will be directly protected if these instream flow applications advance to permit status. Existing (senior) water rights will be unaffected if the proposed water rights are approved because the proposed instream flow rights will have a current day (junior) priority date and water for all senior water rights would be honored in their entirety when water is available according to state law.

The instream flow recommendations to maintain short-term habitat for SRC in Cliff Creek are summarized in TABLE 12 and assume that basic geomorphic characteristics of the stream do not change. Four seasonal time periods were identified for instream flow recommendations. These distinct seasons include winter fish survival (October 1–March 31), an early spring period that is important for longitudinal habitat connectivity in anticipation of SRC spawning (April 1–30), the spring SRC spawning period (May 1–June 30), and the summer months that facilitate trout production potential (July 1–September 30).

Winter flow recommendations were based on a combination of Habitat Retention results and the lowest 20% monthly exceedence value during the winter period for each segment. Early spring recommendations were based on adult and juvenile habitat requirements (determined using the River 2D or PHABSIM). Recommendations for the spring spawning period were based on peak SRC spawning habitat suitability determined using either the River 2D or PHABSIM models. Summer flow recommendations were based on habitat requirements to maintain adult and juvenile trout production. Late summer trout production was determined with the HQI model while the River 2D or PHABSIM model was used to ensure sufficient suitable habitat for other life stages during this season. In a few cases, habitat models indicated that most favorable conditions were greatest for target species / life stages at discharges that are higher than what naturally occurs in that segment. In those instances a different model result was used, or as a last resort, the 20% exceedence flow (the lowest monthly value estimated for the given time period) was recommended.

TABLE 12. Flow recommendations (cfs) for each of the two proposed instream flow segments in Cliff Creek.

Study Segment	**Winter Survival Oct 1 – Mar 31**	**Early Spring Connectivity Apr 1 – Apr 30***	**Spring Spawning May 1 – Jun 30***	**Summer Production Jul 1 – Sep 30**
Lower Cliff Creek	15	45	140	35
Upper Cliff Creek	11	20	20	17

∗ Channel maintenance flow recommendations for the spring runoff period are defined in Appendix A.

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Appendix A. Channel Maintenance Flows

Overall Approach

The term “channel maintenance flows” refers to flows that maintain existing channel morphology, riparian vegetation and floodplain function (US Forest Service 1997, Schmidt and Potyondy 2004). The basis and approach used below for defining channel maintenance flows applies to snowmelt-dominated gravel and cobble-bed (alluvial) streams. By definition, these are streams whose beds are dominated by loose material with median sizes larger than 0.08 in. and with a pavement or armor layer of coarser materials overlaying the channel bed. In these streams, bedload transport processes determine the size and shape of the channel and the character of habitat for aquatic organisms (Andrews 1984, Hill et al. 1991, Leopold 1994).

A flow regime that provides channel maintenance results in stream channels that are in approximate sediment equilibrium, where sediment export equals sediment import on average over a period of years (Leopold 1994, Carling 1995, Schmidt and Potyondy 2004). Thus, stream channel characteristics over space and time are a function of sediment input and flow (US Forest Service 1997). When sediment-moving flows are removed or reduced over a period of years, some gravel-bed channels respond with reductions in width and depth, rate of lateral migration, stream-bed elevation, stream side vegetation, water-carrying capacity, and changes in bed material composition.

Maintenance of channel features and floodplain function cannot be obtained by a single threshold flow (Kuhnle et al. 1999). Rather, a dynamic hydrograph within and between years is needed (Gordon 1995, Trush and McBain 2000, Schmidt and Potyondy 2004). High flows are needed in some years to scour the stream channel, prevent encroachment of stream banks, and deposit sediments to maintain a dynamic alternate bar morphology and a riparian community with diverse successional states. Low flow years are as valuable as high flow years on some streams to allow establishment of riparian seedlings on bars deposited in immediately preceding wet years (Trush and McBain 2000). The natural interaction of high and low flow years maintains riparian development and aquatic habitat by preventing annual scour that might occur from continuous high flow (allowing some riparian development) while at the same time preventing encroachment by riparian vegetation that could occur if flows were artificially reduced at all times.

Channel maintenance flows must be sufficient to move the entire volume and all sizes of material supplied to the channel from the watershed over a long-term period (Carling 1995, Schmidt and Potyondy 2004). A range of flows, under the dynamic hydrograph paradigm, provides this function. Infrequent high flows move large bed elements while the majority of the total volume of material is moved by more frequent but lower flows (Wolman and Miller 1960, Leopold 1994). In streams with a wide range of sediment sizes on the channel boundary, a range of flows may best represent the dominant discharge because different flow velocities are needed to mobilize different sizes of bed load and sediment. Kuhnle et al. (1999) noted “A system designed with one steady flow to transport the supplied mass of sediment would in all likelihood become unstable as the channel aggraded and could no longer convey the sediment and water supplied to it. A system designed with one steady flow to transport the supplied sediment size distribution would in all likelihood become unstable as the bed degraded and caused instability of the banks.”

A bedload transport model (FIGURE A-1) shows the total amount of bedload sediment transported over time (during which a full range of stream discharge (Q) values occur). Smaller discharges, such as the $Q_{threshold}$ (when sediment begins to move) occur more frequently, but not much sediment is moved during those times. The $Q_{effective}$ is the discharge when the greatest volume of sediment is in transport and when some of the larger sediment particles (gravels and small cobbles) move. The bankfull discharge, in which flow begins to inundate the floodplain and which has a return interval of approximately 1.5 years on average, typically occurs near the $Q_{effective}$. The Qcap (the discharge corresponding to the 25-year return interval) represents the upper limit of the required channel maintenance flow regime, since the full range of mobile sediment materials move at flows up to this value, but these higher flows are infrequent. The more frequent discharges that occur between the $Q_{threshold}$ and the $Q_{effective}$ move primarily smaller-sized particles (sand and small gravel) and prevent filling in of pools and other reduction in habitat complexity. Since these particles are deposited into the stream from the surrounding watershed with greater frequency, it is important to maintain a flow regime that provides sufficient conveyance properties (high frequency of moderate discharges) to move these particles through the system. However, alluvial streams, particularly those at higher elevations, also receive significant contributions of larger-sized particles from the surrounding watershed and restrictions to the flow regime that prevent or reduce the occurrence flows greater than $Q_{effective}$ (which are critical in moving coarser materials) would result in gradual bedload accumulation of these larger particles. The net effect would be an alteration of existing channel forming processes and habitat (Bohn and King 2001). For this reason, flows up to the 25-year peak flow are required to maintain existing channel form and critical habitat features for local fish populations.

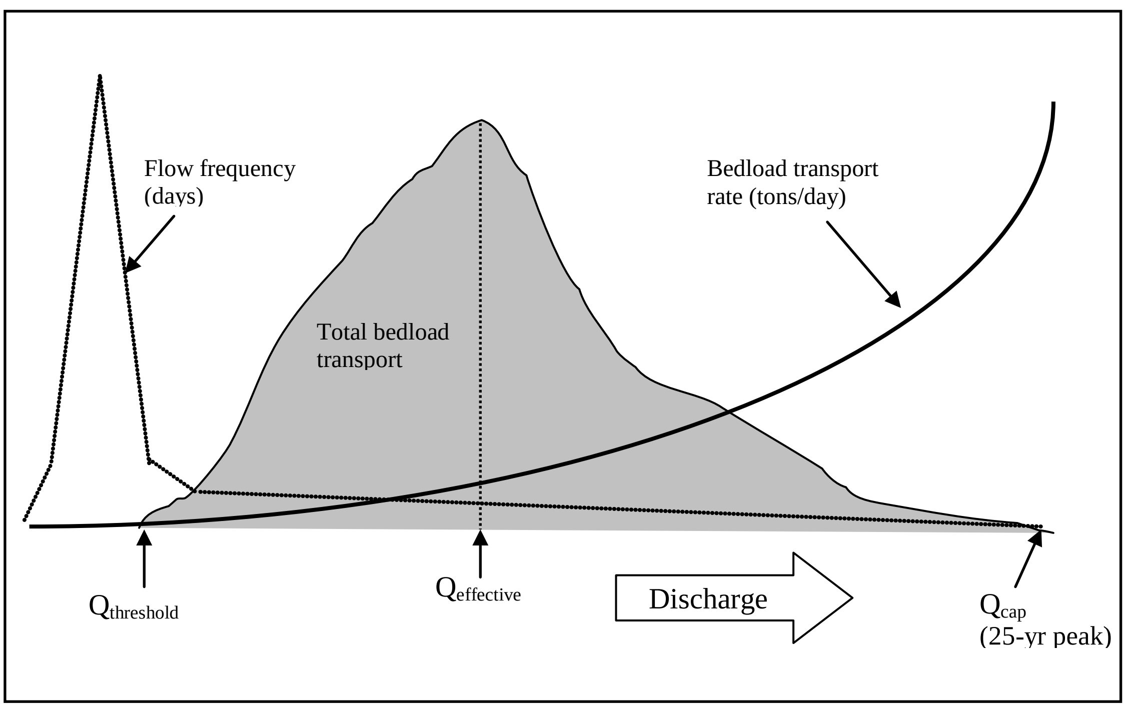

FIGURE A-1. Total bedload transport as a function of bedload transport rate and flow frequency (adapted from Schmidt and Potyondy 2004).

The bankfull flow and average annual flow are two hydrologic variables that can be estimated in streams without the extensive bedload transport data that identify critical flows for initiation of particle transport. With estimates of bankfull flow and average annual flow, the discharges that move small and large particles can be approximated. Initial particle transport begins at flows somewhat greater than average annual flows but lower than bankfull flows (Schmidt and Potyondy 2004). Ryan (1996) and Emmett (1975) found the flows that generally initiated transport were between 0.3 and 0.5 of bankfull flow. Movement of coarser particles begins at flows of about 0.5 to 0.8 of bankfull (Leopold 1994, Carling 1995). Schmidt and Potyondy (2004) discuss phases of bedload movement and suggest that a flow trigger of 0.8 of the bankfull flow "provides a good first approximation for general application" in defining flows needed to maintain channels.

Based on these principles, the following model was developed by Dr. Luna Leopold and is used in this report:

$$Q\ \text{Recommendation} = Q_f + \{(Q_s - Q_f) * [(Q_s - Q_m) / (Q_b - Q_m)]^{0.1}\}$$

Where: Q_s = actual stream flow
Q_f = fish flow (required to maintain fish habitat)
Q_m= sediment mobilization flow = 0.8 * Q_b
Q_b = bankfull flow

The model is the same, with one variation, as the one presented in Gordon (1995) and the Clark's Fork instream flow water right (C112.0F) filed by the U.S. Forest Service with the Wyoming State Engineer. The model presented in those documents used the average annual flow as the flow at which substrate movement begins. This term was re-defined here as the substrate mobilization flow (Q_m) and assigned a value of 0.8 times bankfull flow based on the report by Schmidt and Potyondy (2004).

Channel maintenance flow recommendations developed with this approach requires that only a portion of the flow be maintained in channel for maintenance efforts. When total discharge is less than the sediment mobilization flow of 0.8 times bankfull flow, all of the water above the required fish flows is available for other uses (FIGURE A-2). Similarly, all flows greater than the 25-year recurrence flow are not necessary for channel maintenance and are available for other uses. Between the sediment mobilization flow and bankfull, the model is used to determine what proportion of flow should remain in channel for maintenance activities. For those infrequent flows that occur in the range between bankfull flow and the 25-year recurrence flow, all flow is recommended to remain in the channel for these critical channel maintenance purposes.

Under this "dynamic hydrograph" approach, the volume of water required for channel maintenance is variable from year to year. During low flow years, less water is required for channel maintenance because flows may not reach the defined channel maintenance level. In those years, most water in excess of fish habitat flows is available for other uses. The majority of flow for channel maintenance occurs during wet years. One benefit of this dynamic hydrograph quantification approach is that the recommended flow is needed only when it is available in the channel and does not assert a claim for water that is not there as often happens with a threshold approach.

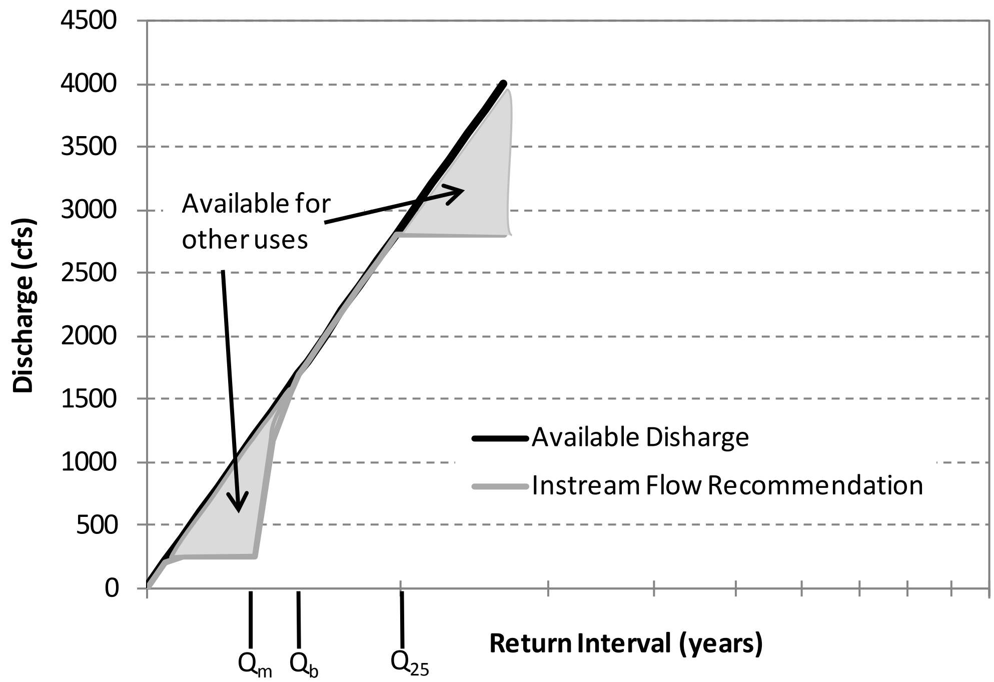

FIGURE A-2. General function of a dynamic hydrograph instream flow for fishery maintenance. Q_m is substrate mobilization flow, Q_b is bankfull flow, and Q_{25} is the discharge with a 25-year return interval.

The Leopold equation model yields a continuous range of instream flow recommendations at flows between the sediment mobilization flow and bankfull for each cubic foot per second increase in discharge (FIGURE A-2). This manner of flow regulation is complex and could prove burdensome to water managers. To facilitate flow administration while still ensuring reasonable flows for channel maintenance, we modified this aspect of the approach to claim instream flows for four evenly partitioned blocks or increments of flow between the sediment mobilization flow and bankfull.

Lower Cliff Creek Segment

Like all properly functioning rivers, Cliff Creek has a hydraulically connected watershed, floodplain, riparian zone, and stream channel. Bankfull and overbank flow are essential hydrologic characteristics for maintaining the habitat in and along these river segments in their existing dynamic form. These high flows flush sediments from the gravels and maintain channel form (i.e., depth, width, and pool and riffle configuration) by periodically scouring encroaching vegetation. Overbank flow maintains recruitment of riparian vegetation, encourages lateral movement of the channel, and recharges ground water tables. Instream flows that maintain the connectivity of these processes over time and space are needed to maintain the existing fishery (Annear et al. 2004).

Applying the Leopold equation and approach yielded channel maintenance recommendations for the lower Cliff Creek instream flow segment (Table 1-1). The base, or fish, flow used in the analysis was the spawning flow (140 cfs). For naturally available flow levels less than the spawning flow, the channel maintenance instream flow recommendation is equal to natural flow. The spawning flow level is substantially less than the substrate mobilization flow (398 cfs). For the flow range between the spawning flow and the substrate mobilization flow, the channel maintenance flow recommendation is equal to the spawning flow (Table 1-1). When naturally available flows range from the substrate mobilization flow volume to the bankfull flow volume, the Leopold formula is applied and results in incrementally greater amounts of water applied toward instream flow (Table 1-1). At flows between bankfull and the 25-year flood flow, all stream flow is retained in the channel to perform maintenance functions. At flows greater than the 25-year flood flow, only the 25-year flood flow is needed for channel maintenance because this flow level will have moved the necessary amount of bed load materials and reconnected the channel with the floodplain (FIGURE A-3).

TABLE A-1. Channel maintenance instream flow recommendations (May 1–June 30) to maintain existing channel forming processes and long-term aquatic habitat characteristics in the lower Cliff Creek instream flow segment.

Flow Level Description	**Available Flow (cfs)**	**Recommended Flow (cfs)**
<Spawning Flow*	<140	<140
Spawning Flow	140	140
<Substrate Mobilization Flow	141-397	140
Substrate Mobilization Flow	398	140
Mobilization to Bankfull	399-423	304
Mobilization to Bankfull	424-448	388
Mobilization to Bankfull	449-473	429
Mobilization to Bankfull	474-497	465
Bankfull Flow	498	498
Bankfull Flow to 25-Year Flood[#]	498-2461	498-2461
25-Year Flood	2461	2461
> 25-Year Flood	≥ 2461	2461

*At stream flows less than the spawning flow, the flow recommendation is all available flow.
Between bankfull and the 25-year flow, the flow recommendation is all available flow.

FIGURE A-3 shows examples of channel maintenance flow recommendations implemented in randomly selected average and wet years. Dry years are not shown because flows would not exceed the 398 cfs substrate mobilization threshold to initiate channel maintenance flows. In the representative average year, 1989, flow exceeded substrate mobilization flow on 10 days, which would trigger channel maintenance flow recommendations. In the representative wet year, 1986, these recommendations would apply for 30 days in May and June (FIGURE A-3).

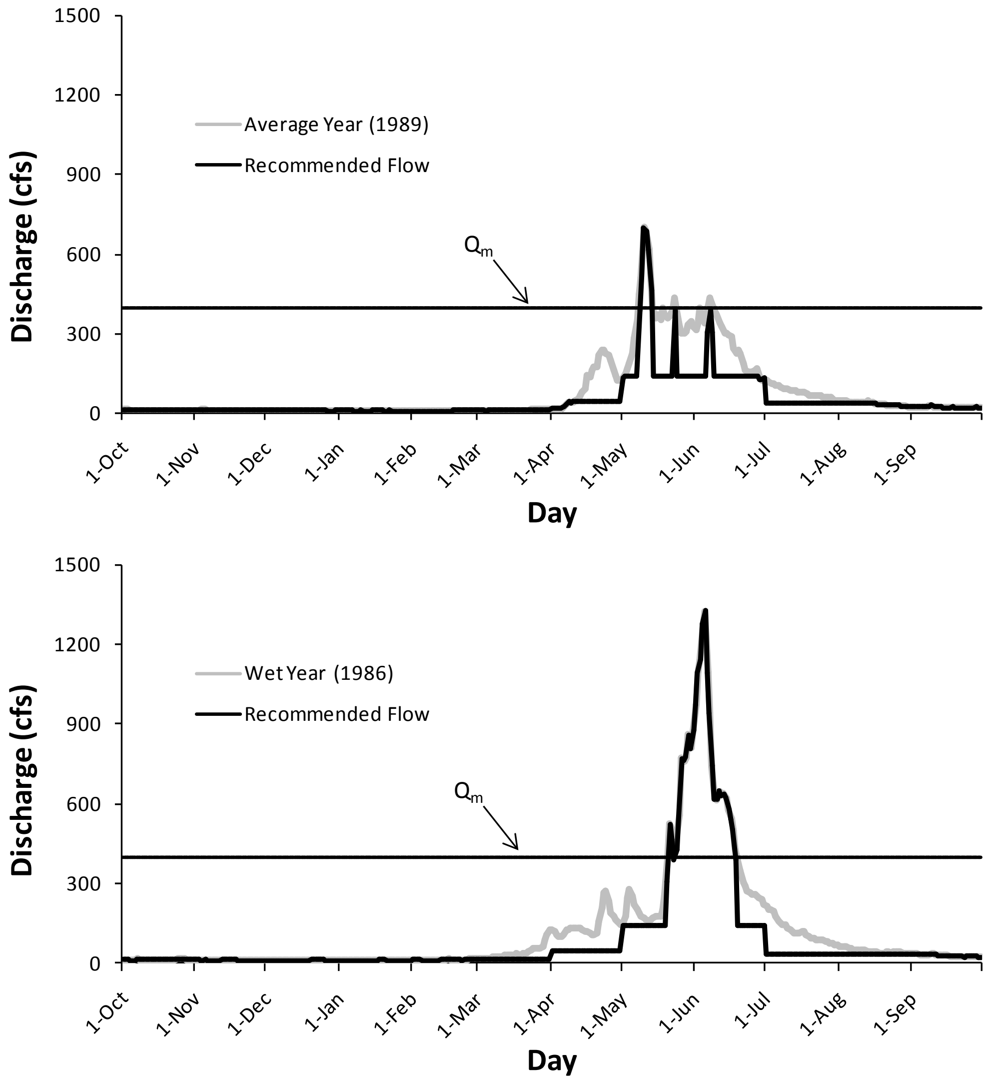

FIGURE A-3. Channel maintenance flow recommendations and hydrographs for the lower Cliff Creek instream flow segment in an average (1989) and a wet (1986) water year.

If water storage were developed (though it is not recommended for this fishery) it would be necessary to further specify the rate at which releases could be increased or decreased to the channel maintenance or spawning levels. The sharp flow increases and decreases evident in FIGURE A-3 (e.g., 140 cfs to 304 cfs in one day) would cause habitat loss through excessive scour and potential trout mortality due to stranding. More gradual changes akin to a natural hydrograph would be recommended. In that case, the Index of Hydrologic Alteration (IHA; Richter et al. 1996) could provide a valuable reference. Daily increases and decreases during runoff measured at the Little Granite Creek gage (HabiTech 2009) could serve as a guide for developing such ramping rate recommendations using the IHA.

Upper Cliff Creek Segment

Applying the Leopold equation and approach yielded channel maintenance recommendations for the upper Cliff Creek instream flow segment (Table 1-2). The base or fish flow used in the analysis was the spawning flow (60 cfs). For naturally available flow levels less than the spawning flow, the channel maintenance instream flow recommendation is equal to natural flow. The spawning flow level is considerably less than the substrate mobilization flow (279 cfs). For the flow range between the spawning flow and the substrate mobilization flow, the channel maintenance flow recommendation is equal to the spawning flow (Table 1-2). When naturally available flows range from the substrate mobilization flow to the bankfull flow level, application of the Leopold formula results in incrementally greater amounts of water applied toward instream flow (Table 1-2). At flows between bankfull and the 25-year flood flow, all stream flow is needed to perform channel maintenance functions. At flows greater than the 25-year flood flow, only the 25-year flood flow is needed for channel maintenance because this flow level will have moved the necessary amount of bed load materials and reconnected the channel with the floodplain (FIGURE A-4).

TABLE A-2. Channel maintenance instream flow recommendations (May 1–June 30) to maintain existing channel forming processes and long-term aquatic habitat characteristics in the upper Cliff Creek instream flow segment.

Flow Level Description	Available Flow (cfs)	Recommended Flow (cfs)
<Spawning Flow*	<20	<20
Spawning Flow	20	20
<Substrate Mobilization Flow	21-278	20
Substrate Mobilization Flow	279	20
Mobilization to Bankfull	280-297	190
Mobilization to Bankfull	298-314	263
Mobilization to Bankfull	315-332	296
Mobilization to Bankfull	333-348	324
Bankfull Flow	349	349
Bankfull Flow to 25-Year Flood[#]	349-1722	349-1722
25-Year Flood	1722	1722
> 25-Year Flood	≥ 1722	1722

*At stream flows less than the spawning flow, the flow recommendation is all available flow.
Between bankfull and the 25-year flow, the flow recommendation is all available flow.

FIGURE A-4 shows examples of channel maintenance flow recommendations implemented in randomly selected average and wet years. Dry years are not shown because flows would not exceed the 279 cfs substrate mobilization threshold to initiate channel maintenance flows. In the representative average year, 1989, flow exceeded substrate mobilization on 10 days, which would trigger channel maintenance flow recommendations. In the representative wet year, 1986, these recommendations would apply for 30 days in May and June (FIGURE A-4).

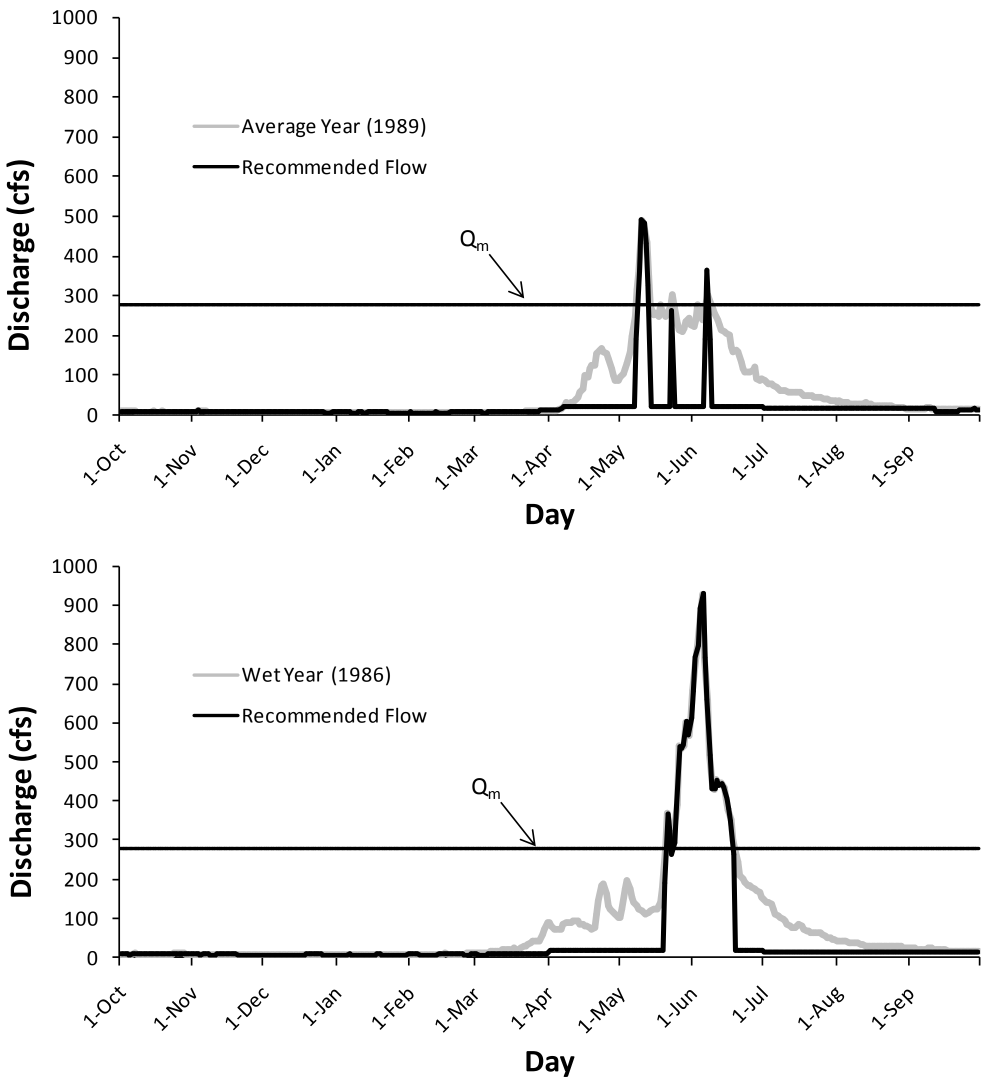

FIGURE A-4. Channel maintenance flow recommendations and hydrographs for the lower Cliff Creek instream flow segment in an average (1989) and a wet (1986) water year.

If water storage were developed (though it is not recommended for this fishery) it would be necessary to further specify the rate at which releases could be increased or decreased to the channel maintenance or spawning levels. The sharp flow increases and decreases evident in FIGURE A-4 (e.g., 20 cfs to 190 cfs in one day) would cause habitat loss through excessive scour and potential trout mortality due to stranding. More gradual changes akin to a natural hydrograph would be recommended. In that case, the Index of Hydrologic Alteration (IHA; Richter et al. 1996) could provide a valuable reference. Daily increases and decreases during runoff measured at the Little Granite Creek gage (HabiTech 2009) could serve as a guide for developing such ramping rate recommendations using the IHA.